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The Mephisto Conceptual Framework

Dale Lambert and Chris Nowak

Command, Control, Communications and Intelligence Division
Defence Science and Technology Organisation

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ABSTRACT

This document provides an overview of concepts currently associated with the Mephisto conceptual framework. The Mephisto framework is designed to facilitate machine-based representation and reasoning in the military and national security domains. The conceptualisation introduces metaphysical, environmental, functional, cognitive and social constructs that can be integrated to describe aspects of interest in a military or national security context.

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Executive Summary

Information fusion refers to the process whereby machines utilise one or more data sources over time to assemble a representation of aspects of interest in an environment. Historically, the data sources were confined to conventional sensors. However, the rise of terrorism and network centric warfare over the last decade has expanded the scope of information fusion beyond conventional sensor data, with the aspects of interest in the environment now also including biographical, economic, social, transport and telecommunications, geographic, military, political and technical information. One challenge introduced by this transition is how to represent these types of information within a machine so that the machine is able to meaningfully inform its users.

The Mephisto conceptual framework is being developed by the Defence Science and Technology Organisation (DSTO) to represent these types of information within a machine so that it can support machine-based reasoning about the military and national security domains. The conceptualisation introduces metaphysical, environmental, functional, cognitive and social constructs that can be integrated to describe the various aspects of interest in a military or national security context. This document catalogues the concepts currently utilised within the Mephisto framework, without addressing associated formal logics or computational implementations in any detail. The Mephisto framework can express a diversity of ideas, ranging from the identities of objects in space and time through to complex arrangements for command and control.

Authors

Dr. Dale Lambert
Command, Control, Communications and Intelligence Division

Dr. Dale Lambert is Head of the DSTO Fusion for Situation Awareness Initiative. The DSTO Fusion for Situation Awareness Initiative is a cross divisional long-range research programme directed at understanding the defence and national security information fusion requirement in the network centric environment, with a view to consolidating existing, and innovating new, science and technology to address these requirements.

Dr. Chris Nowak
Command, Control, Communications and Intelligence Division

Dr. Chris Nowak is Deputy Head of the DSTO Fusion for Situation Awareness Initiative. He received his Ph.D. degree from the University of Adelaide in 1998. He began at DSTO in 1998 as a research scientist in the Information Technology Division working on defence-related knowledge representation activities. In April, 2007, he joined the Fusion for Situation Awareness Initiative, which is attached to C3I Division. His research interests include knowledge representation and reasoning, formal ontologies and logics, and information fusion.

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1. Introduction

1.1 Data Fusion

In [1] and [2], Lambert defines data fusion broadly as

> … the process of utilising one or more data sources over time to assemble a representation of aspects of interest in an environment.

The traditional roots of the data fusion community are in sensor fusion, where the "data sources" are established sensors and the "aspects of interest in the environment" are moving objects, each typically represented by a set of state vectors. The broader definitions reflect an increasing emphasis toward generalizing sensor fusion into so called higher-level fusion, in which "the aspects of interest in the environment" are not restricted to objects, but include biographic, economic, social, transport and telecommunications, geographic, military, political and technical information

The Joint Directors of Laboratories (JDL) model was proposed in the late 1980s ([3]), with various revisions of it (e.g. [4], [5], [6], [7]) serving as the dominant model for data fusion. Figure 1 illustrates a variant of its revised form ([5]).

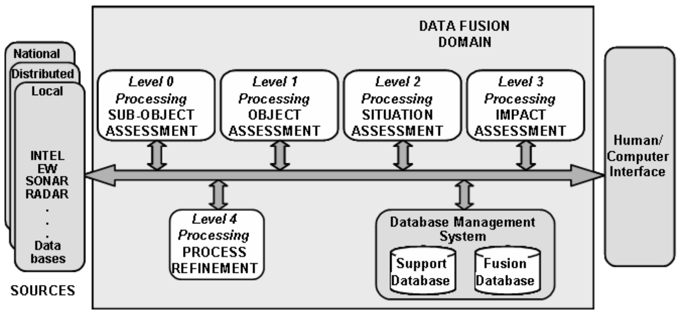

Figure 1: A revised JDL model of data fusion

The elements of the model are as follows:

- The source data provides representations of the world in numeric, graphic or symbolic form and can include surveillance, intelligence, public and other information.
- The sub-object assessments provide representations of detections of objects in the world, typically through numeric signal and/or image processing.
- The object assessments provide representations of objects in the world, typically through numerically based detection tracking and sensor fusion processing.
- The situation assessments provide representations of relations of interest between objects of interest in the world, typically through symbolic and some numeric processing, where the relations of interest can vary widely from concrete geospatial relations through to abstract political relations.

- The impact assessments provide representations of the consequences of interest from the representations of relations of interest between objects of interest in the world, typically through symbolic and some numeric processing, and involving threat assessments, course of action assessments and the like.
- The process refinements involve dynamic adaptations to sub-object, object, situation and impact processing, while also considering dynamic adaptations to sensor control.
- Databases are required to store the various representations.
- The system also needs to be able to interface with its human users.

1.2 Semantic Challenge

When contemplating machine-based situation assessments, one confronts the question: "What symbols should be used and how do those symbols acquire meaning?" - termed "the Semantic Challenge" for Information Fusion by Lambert ([2]). The fusion system requires a means of representing the domain of interest in a meaningful way. The challenge is substantial in the military and national security domain. Even a simple scenario is likely to involve:

- nations and conflicts;
- physical geography;
- moving objects;
- military equipment with certain capabilities;
- civilian maritime and air traffic;
- masked intents – a military "chess game".

In response, in relation to the Future Operations Centre Analysis Laboratory (FOCAL) task, Lambert [2] offered the following table in the context of the military and national security domain.

Social:	group, ally, enemy, neutral, own, possess, invite, offer, accept, authorise, allow.
Intentional:	individual, routine, learnt, achieve, perform, succeed, fail, intend, desire, belief, expect, anticipate, sense, inform, effect, approve, disapprove, prefer.
Functional:	sense, move, attack, attach, inform, operational, disrupt, neutralise, destroy.
Physical:	land, sea, air, outer_space, incline, decline, number, temperature, weight, energy.
Metaphysical:	exist, fragment, identity, time, before, space, connect, distance, area, volume, angle.

The physical, functional and intentional layers were motivated by Dennett's ([8]) physical, design and intentional stances respectively in which he argues that individuals will seek to predict and explain an entity on the basis of naïve physics where possible, then on the basis of the entity's design if the physical stance is unsuccessful, and then on the basis of a cognitive stance toward the entity if the design stance is unsuccessful. To this Lambert ([2]) added a metaphysical layer below, a social layer above, and contemplated the nature of the relations that occupy each layer, with each reliant on relations from the layers below. The Physical Layer was subsequently renamed as the Environmental Layer. The Intentional Layer was subsequently renamed as the Cognitive Layer ([9]). Based *loosely* on the names of its layers

Metaphysical, Physical, Functional, Intentional, Social, Nowak ([10]) introduced the term "Mephisto" for the conceptual framework.

The role of each layer is outlined in [9],

> The *Metaphysical Layer* introduces foundational concepts like existence, identity, space and time. This allows the machine to identify fragments of the environment of interest and to do so with respect to their spatiotemporal parts. The *Environmental Layer* introduces environmental properties and relations to the metaphysical parts. This allows the machine to ascribe attributes like temperature and weight to individuated parts, while identifying some parts as ocean, others as land, and so on. The *Functional Layer* considers the functionality of identified physical parts. Principal functional relations in a military context are the ability to sense, move, strike, attach (includes carry), inform and transform. These are sufficient to characterise: surveillance and reconnaissance, weapons, logistics, communications and engineering capabilities. The *Cognitive Layer* adds cognitive relations to the identified physical and functional spatiotemporal parts. The attribution of beliefs, intentions and other mental states is performed at the Cognitive Layer. Finally, the *Social Layer* introduces social constructs between the cognitive individuals. Concepts like authority and enemy prevail at the Social Layer.

This document provides a very limited motivation for, and overview of, the concepts currently associated with Mephisto. As an ontological framework, Mephisto is *prescriptive*, rather than *descriptive*, in that it attempts to provide a philosophically well-grounded approach, rather than a natural language-oriented conceptualisation ([11]). Mephisto is also a *reductionist*, rather than a *multiplicative* approach, in that it seeks to identify a small number of primitive terms that are sufficient to account for the five layers in the intended context. As information fusion involves more than the mere aggregation of information, a reductionist framework is to be expected, though the extent of reductionism can vary. The focus taken is also on meaning. As outlined in [12], the primitive concepts are to be formalised in a logic to make the meanings of those terms precise, and then implemented within a machine with a logical reasoner. This allows a machine to reason meaningfully with those concepts. Although first order logic and description logic formal theories have been explored for aspects of the Mephisto conceptualisation, *this document considers neither the formal nor computational aspects in any serious detail. Its aim is to simply to catalogue the concepts currently under consideration*.

2. Metaphysical

2.1 Existence and Identity

2.1.1 Nominalism

Existence and identity are two of the most basic aspects of the world that need to be represented. Does an aircraft *exist* at a particular location and is it the *same* aircraft that was detected at a previous location, are simple examples of the need for existence and identity concepts in the military and national security context. Philosophically the Mephisto Metaphysical Layer promotes a nominalist, rather than a realist, standpoint toward the world ([13]). Thus universals, like red and bigger, are not admitted as things in the world. The things of the world are instead confined to what we might term "bare matter", and the only things that exist are (non-empty) fragments of that matter. Formally this trades an intensional world for an extensional Boolean algebra universe, and in the preferred Anaxagorous formalisation, an atomless Boolean algebra ([13]).

Figure 2: A military scene

To illustrate, a realist might accept sets of objects as things in the world and so might represent the scene in Figure 2 as

{field, sky, foliage, {main_rotor, tail_rotor, fuselage}, truck1, container1, truck2, container2, soccer_goals},

having first represented the scene by

{field, sky, foliage, helicopter, truck1, container1, truck2, container2, soccer_goals},

and then noted that

helicopter = {main_rotor, tail_rotor, fuselage}.

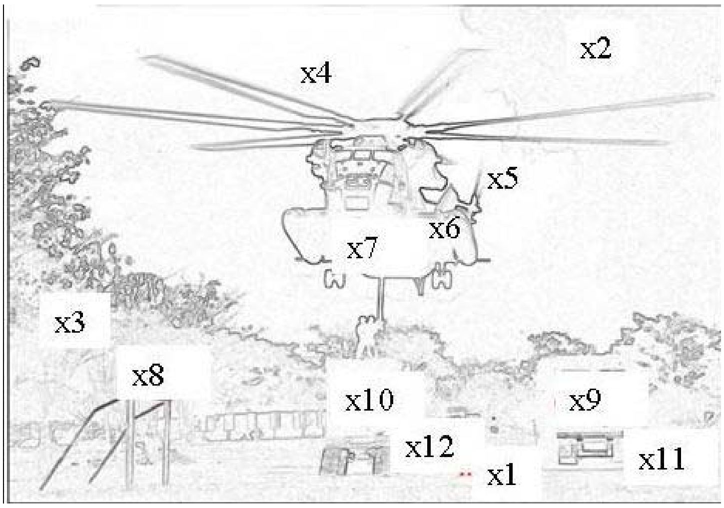

Figure 3: A nominalist view of a military scene

The nominalist, by contrast, will replace these set theoretic complexes by peeling away the properties and relations used to identify the "bare matter" of interest (Figure 3), label those fragments of "bare matter", and then recover the information through facts stating relations between the identified "bare matter". The result is something like the following

> field(x1) & sky(x2) & foliage(x3) & main_rotor(x4) & tail_rotor(x5) & fuselage(x6) & helicopter(x7) & x7 ≡ x4 + x5 + x6 & soccer_goals(x8) & container(x9) & container(x10) & truck(x9) & truck(x10).

2.1.2 Nominalist Concepts

Identity, denoted by ≡, is simply the equality construct in the Boolean algebra, so that x is identical to y if and only if x and y are the same piece of "bare matter". Nothing, denoted by ⊥, is the bottom element of the Boolean algebra. Existence is defined as not being nothing, formally by **exists**(x) $=_{df}$ ¬(x ≡ ⊥). The Mephisto concepts related to existence and identity feature in Figure 4. A formal theory for these concepts has been defined ([13]).

Relation	Type	Primitive	Phrase
x ≡ y	relation	Y	x is identical to y
x ≤ y	relation	Y	x is a fragment of y
Ω	constant	N	everything
x + y	function	N	x joined with y
x • y	function	N	x meeting with y
x - y	function	N	x without y
-x	function	N	without x
⊥	constant	N	nothing
exists(x)	relation	N	x exists

Figure 4: Concepts for Existence and Identity

2.2 Time

2.2.1 Perdurantism

A second fundamental concept is time. A primary choice is between endurantism and perdurantism ([14]).

- The endurantist holds that an identity can exist at different times, that an identity is an enduring object. Consequently the endurantist must confront the problem of how an enduring object can change and yet still be the same (identity) object. The endurantist understands change in terms of things.
- The perdurantist holds that an identity is formed from different things at different times, that an identity is a process, an assembly of different temporal parts. Consequently the perdurantist must confront the problem of how temporally different things can belong to the same (identity) thing. The perdurantist understands things in terms of change.

The Mephisto framework embraces a perdurantist standpoint and so treats every thing as a process. Identity is therefore often described as a sum of its temporal parts, e.g.

$$\text{dale} \equiv (\text{dale} \bullet \text{before\_today}) \mathbf{+} (\text{dale} \bullet \text{today}) \mathbf{+} (\text{dale} \bullet \text{after\_today}).$$

Times are admitted within the nominalist framework through a function **time**, so that the time of x, **time**(x), is a fragment of the nominalist universe. The time of nothing is nothing, and so **time**($\perp$) $\equiv \perp$. Otherwise the time of y is the fragment of the universe containing all fragments which share the same time, i.e.

$$\forall x\ \forall y\ (x \leq \mathbf{time}(y) \Leftrightarrow \exists u\ (u \leq y\ \&\ \mathbf{time}(u) \equiv \mathbf{time}(x))).$$

Thus ontologically, temporal fragments contain all fragments which share the same time. Formally this makes the temporal processes a subalgebra of the Boolean algebra of existence and identity.

Temporal processes are defined as unbounded, densely, linearly ordered structures under the Mephisto framework. This allows for some things to occur before others. This is achieved through the introduction of an **until** primitive in which **until**(x) is all of time until x no longer exists. Contiguous temporal periods of time can be identified from this, with **period**(x) meaning that x is a fixed point of a **duration** function. Allen's temporal interval logic ([15]) can be applied to temporal periods, with Allen's **meets**, **before**, **after**, **during**, **starts**, **finishes**, and **same_time** relations being definable. An unpublished formal theory extension of existence to include time has been developed.

Relation	Type	Primitive	Phrase
time(x)	function	Y	the time of x
temporal(x)	relation	N	x is temporal (composed of coincident fragments)
until(x)	function	Y	the time until x no longer exists
past(x)	relation	N	x has an unlimited past
since(x)	function	Y	the time since x began
future(x)	relation	N	x lasts forever
duration(x)	function	N	the duration of x
period(x)	relation	N	x is a period of time
meets(x, y)	relation	N	y occurs as soon as x finishes
before(x, y)	relation	N	x occurs some time before y
after(x, y)	relation	N	x occurs some time after y
during(x, y)	relation	N	x starts after y and finishes before y
starts(x, y)	relation	N	x starts with y but finishes before y
finishes(x, y)	relation	N	x finishes with y but starts after y
same_time(x, y)	relation	N	x occurs exactly when y occurs

Figure 5: Concepts for Time

2.2.2 Temporal Measure

Quantitative temporal reasoning is also necessary for the military and national security domain, and so the ISO 8601 time standard is included within the Mephisto framework. This allows for calculation in terms of timestamps expressed in terms of years, months, days, hours, minutes and decimal seconds. This provides a temporal measure at a level of granularity without excluding others of different granularity or level of formality.

Relation	Type	Primitive	Phrase
[0, ∞)	constants	Y	tokens for years
{01, …, 12}	constants	Y	tokens for months
{01, …, 31}	constants	Y	tokens for days
{00, …, 23}	constants	Y	tokens for hours
{00, …, 59}	constants	Y	tokens for minutes
[00, 60)	constants	Y	tokens for seconds
seconds(v)	function	Y	the value v in seconds
timestamp(Y,M,D,H, MI,S)	function	Y	the time with year Y, month M, day D, hour H, minute Mi and seconds S
now(t)	function	Y	the timestamp t of the current time
timeperiod(D,H,MI,S)	function	N	all times with day D, hour H, minute Mi and second S
coincide(t_1,t_2)	relation	N	timestamp t_1 coincides with timestamp t_2
prior(t_1,t_2)	relation	N	timestamp t_1 occurs prior to timestamp t_2
same_ timeperiod(τ_1,τ_2)	relation	N	τ_1 is the same time period as τ_2
shorter_ timeperiod(τ_1,τ_2)	relation	N	τ_1 is a shorter time period than τ_2
add_ time(t_1, τ_2, t_3)	relation	N	timestamp t_3 is the addition of timestamp t_1 and time period τ_2
add_ time(τ_1, τ_2, τ_3)	relation	N	time period τ_3 is the addition of time period τ_1 and time period τ_2
subtract_ time(t_1, t_2, τ_3)	relation	N	time period τ_3 is the subtraction of timestamp t_2 from timestamp t_1
subtract_ time(t_1, τ_2, t_3)	relation	N	timestamp t_3 is the subtraction of time period τ_2 from timestamp t_1
subtract_ time(τ_1, τ_2, τ_3)	relation	N	time period τ_3 is the subtraction of time period τ_2 from time period τ_1
multiply_ time(τ_1, c, τ_3)	relation	N	time period τ_3 is the multiplication of time period τ_1 by constant c

Figure 6: Concepts for Temporal Measure[1]

2.3 Space

2.3.1 Ontology, Topology and Orientation

Space is the third metaphysical category within Mephisto. The ontological approach taken is analogous to that of time, with the space of y being the fragment of the universe that contains all fragments which share the same space. The Adelaide Town Hall, for example, is the same region of space across different times. The spatial processes thus form a subalgebra of the Boolean algebra of existence and identity, but in a different dimension from the temporal processes.

Beyond the ontological character of space there are topological, orientation and metric issues to consider. Mephisto currently embraces a Boolean Connection Algebra approach ([16]). This conceptualises space in terms of a Boolean algebra, which is taken to be the spatial subalgebra

[1] Note that some of these predicates are polymorphic in that they allow the same predicate name to be applied with different argument types.

from the Mephisto perspective, and connection axioms expressed in terms of the primitive **connects**. This is sufficient to recover the Region-Connection Calculus operators like **part**, **proper_part**, **overlaps**, **externally_connects** and **non_tangential_proper_part**. Qualitative/quantitative orientation is possible through the 32 north, south, east, and west compass regions illustrated in Figure 8 ([17]). Again, this provides an appropriate conception of orientation for the domain of defence and national security.

Relation	Type	Primitive	Phrase
space(x)	function	Y	the space of x
spatial(x)	relation	N	x is spatial
connects(x, y)	relation	Y	x connects with y
above(x, y)	relation	Y	x is above y
below(x, y)	relation	N	x is below y
centroid(x)	function	Y	the centroid of region x
north(x)	function	Y	the region north of x
north_east(x)	function	Y	the region north east of x
north_west(x)	function	Y	the region north west of x
nor_north_east(x)	function	Y	the region nor north east of x
nor_north_west(x)	function	Y	the region nor north west of x
north_by_east(x)	function	Y	the region north by east of x
north_by_west(x)	function	Y	the region north by west of x
north_east_ by_north(x)	function	Y	the region north east by north of x
north_west_ by_north(x)	function	Y	the region north west by north of x
east_nor_east(x)	function	Y	the region east nor east of x
west_nor_west(x)	function	Y	the region west nor west of x
north_east_ by_east(x)	function	Y	the region north east by east of x
north_west_ by_west(x)	function	Y	the region north west by west of x
east_by_north(x)	function	Y	the region east by north of x
west_by_north(x)	function	Y	the region west by north of x
… as above for south			
south(x)	function	Y	the region south of x
west(x)	function	Y	the region west of x
east(x)	function	Y	the region east of x
connects(x, y)	relation	Y	x connects with y
contiguous(x)	function	N	the contiguous extension of x
region(x)	relation	N	x is a region of space
part(x, y)	relation	N	x is a part of y
proper_part(x, y)	relation	N	x is a proper part of y
overlaps(x, y)	relation	N	x overlaps with y
externally_ connects(x, y)	relation	N	x externally connects with y
non_tangential_ proper_part(x, y)	relation	N	x is a non tangential proper part of y

Figure 7: Concepts for Space

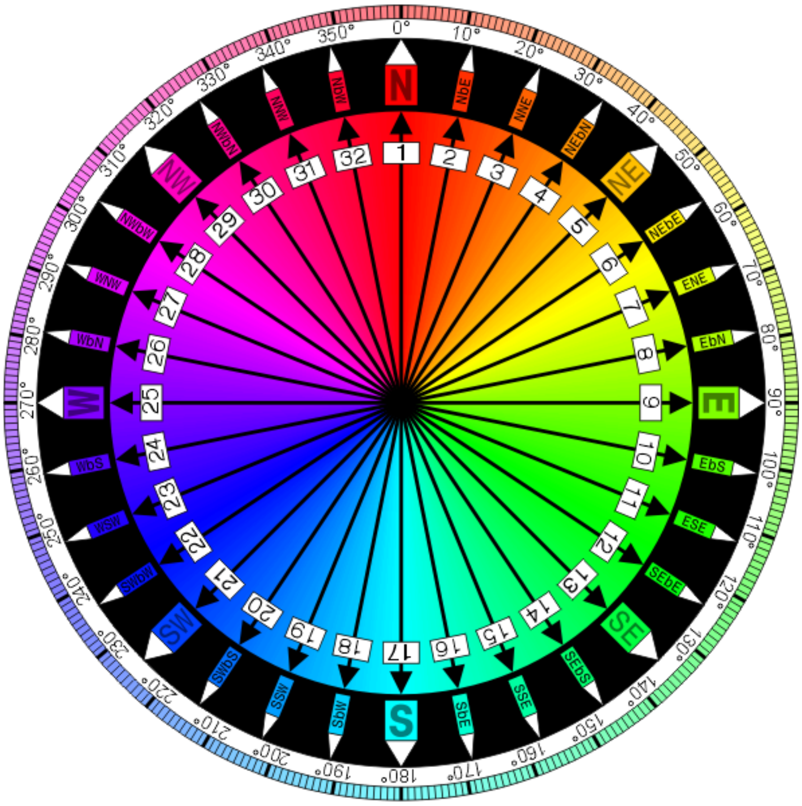

Figure 8 Compass Regions

The following also allows parts of the world to be identified while retaining the component identity, time and space aspects. This, for example, allows the Allen temporal operators in Figure 5 or the Region-Connection Calculus operators in Figure 7 to be applied separately.

Relation	Type	Primitive	Phrase
@(x, t, s)	function	N	the process x at time t at location s (i.e. x • t • s, which may be ⊥)
at(x, t, s)	relation	N	x is at location s at time t (i.e. ¬(x • t • s ≡ ⊥)).

Figure 9: At Reference

2.3.2 Spatial Measure

A metric space is also introduced into Mephisto in the form of the great circle distance over a latitude, longitude and altitude coordinate system. Surface angle, cross track distance and coordinate translation are also included. This provides spatial measure concepts relevant for some aspects of the defence and national security domain. Constants for true north, true south, *et cetera*, are introduced for specific angles, so that the previously qualitative orientations can also be expressed as measured angular intervals.

Relation	Type	Primitive	Phrase
$[-\frac{\pi}{2}, \frac{\pi}{2}]$	constants	Y	tokens for latitudes in radians
$[-\pi, \pi]$	constants	Y	tokens for longitudes in radians
$(-\infty, \infty)$	constants	Y	tokens for altitudes in metres
$[0, \infty)$	constants	Y	tokens for distances in metres
metres(v)	function	Y	the value v in metres
radians(v)	function	N	the value v in radians
coordinate(Lat, Long, Alt)	function	Y	the location with latitude Lat, longitude Long and altitude Alt
distance(c_1, c_2 ,d)	relation	N	the distance between coordinate c_1 and coordinate c_2 is d metres
angle(c_1, c_2 , r)	relation	N	the surface angle between coordinate c_1 and coordinate c_2 is r radians
cross_ track_ distance(c_1, c_2 , c_3 ,xtc, atc)	relation	N	the location on the surface line through coordinate c_1 and coordinate c_2 that is the minimum surface distance from c_3 is xtc metres from c_3 and is atc metres along that surface line from c_1
translate_ coordinate(c_1, d, a, c_2)	relation	N	the translation of coordinate c_1 by d metres in the surface direction of a radians is coordinate c_2
true_north(x)	function	Y	the line north of x
true_north_east(x)	function	Y	the line north east of x
true_north_ west(x)	function	Y	the line north west of x
…			

Figure 10: Concepts for Spatial Measure

3. Environmental

3.1 Environmental Taxonomy

The Environmental Layer characterises types of processes. At the highest level, environmental elements are characterised as natural or artificial. Analogous to Empedocles' earth, air, fire and water, the natural environment begins with land, air, outer_space and water, while the artificial could include engineered infrastructure, including aspects of the cyber environment. The Environmental Layer involves a taxonomy that classifies artificial and natural features of the environment. A sample Environmental Layer developed by Nowak appears in Figure 11.

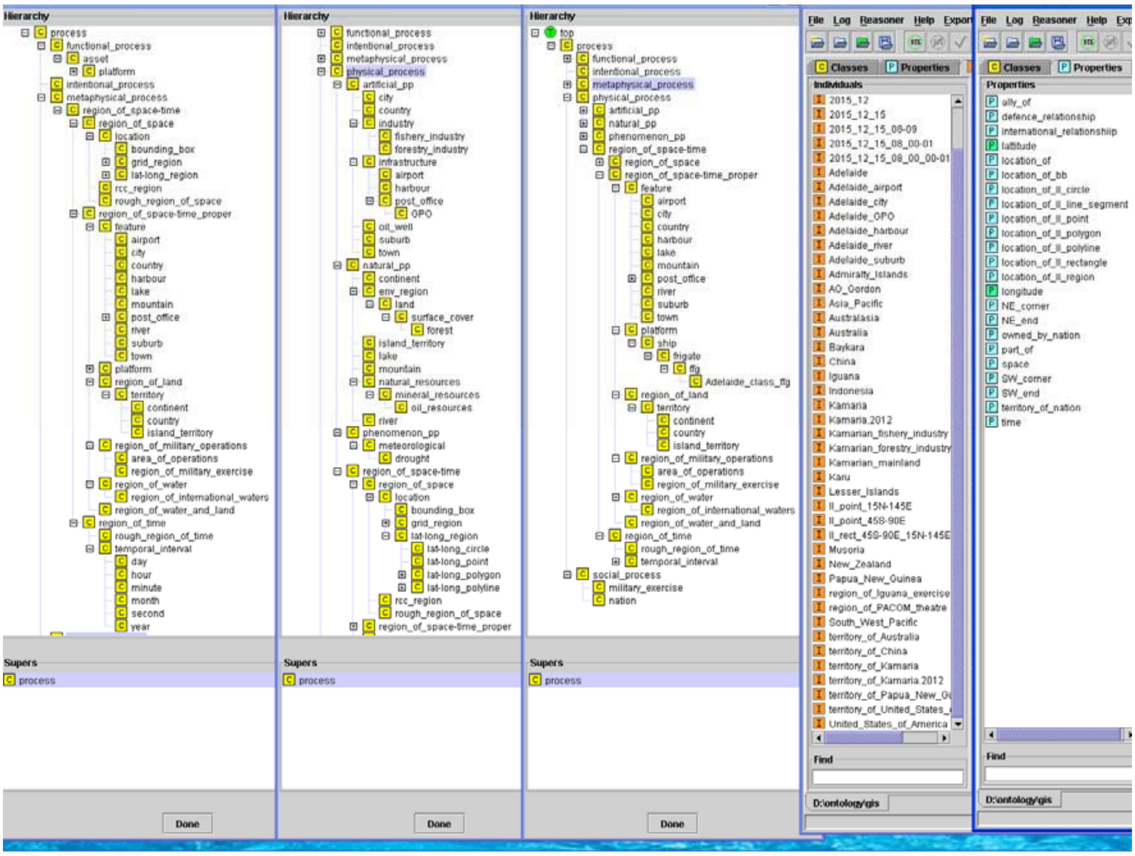

Figure 11: Environmental Ontology

This includes constraints. For example, an important property of water from Figure 12 is that $\forall x\ \forall u\ ((u \leq x\ \&\ \mathbf{water}(x)) \Rightarrow \mathbf{water}(u))$. Naïve physics considerations about liquids might also be applicable, depending upon the level of detail required for a particular context. The choice of environmental taxonomy is shaped by the domain of interest.

Relation	Type	Primitive	Phrase
natural(x)	relation	Y	x is natural
artificial(x)	relation	Y	x is artificial
land(x)	relation	Y	x is land
water(x)	relation	Y	x is water
air(x)	relation	Y	x is air
outer_space(x)	relation	Y	x is outer space
…	relation	N	…

Figure 12: Environmental Concepts

The formal construction associated with these predicates can also vary with the resolution of the domain of interest. For example, a coarse model of an environment that ignores caves and the like appears in Figure 13, with land composed of upland and submerged land. This brings with it some important connection presumptions, for example, **connects**(air, water) but ¬**connects**(water, outer_space).

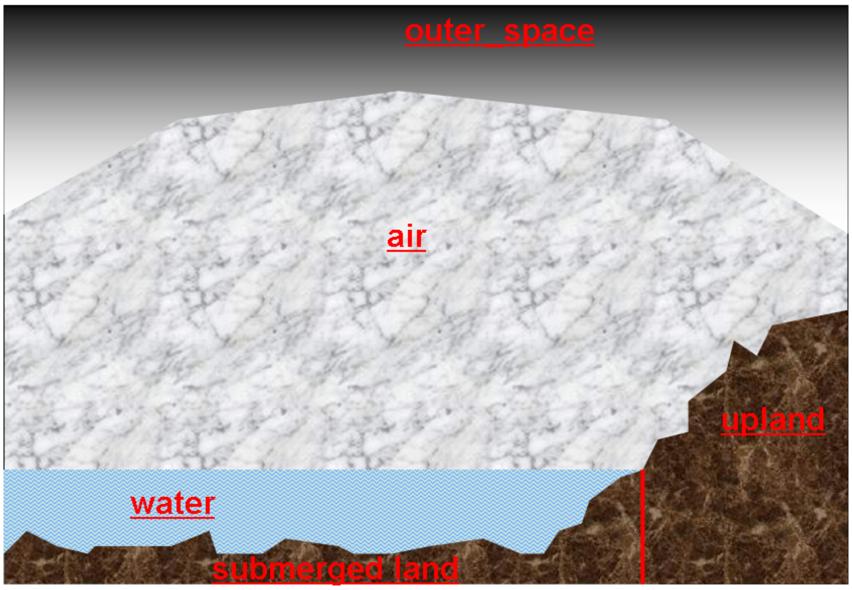

Figure 13: Environment Elements

A labelling of (self-connected) surface regions, as available through a geographic information system for example, gives rise to a labelling of surface extensions, as illustrated in Figure 14.

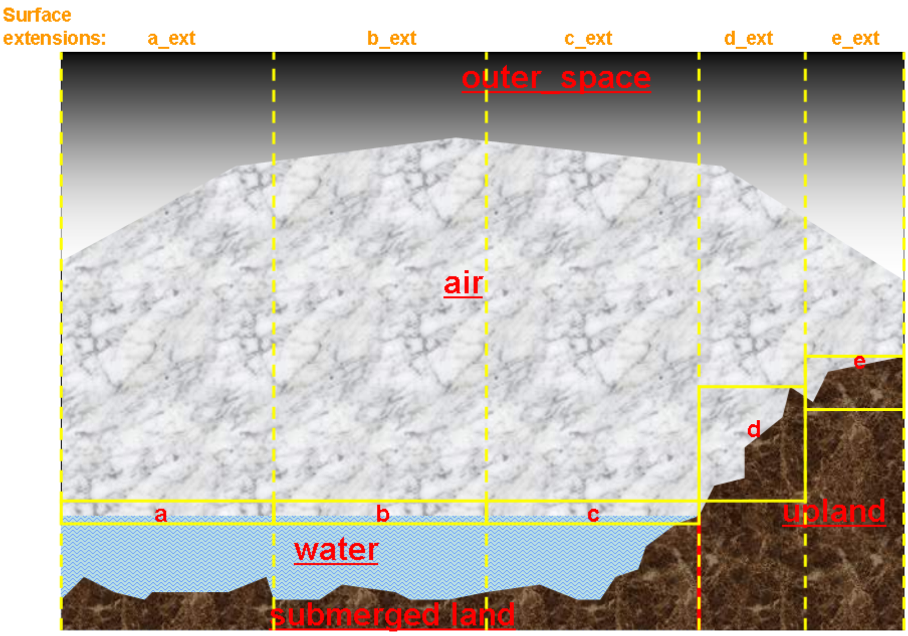

Figure 14: Surface Extensions

Regions of surface extensions can then be identified through use of the metaphysical operators of section 2.1.2. Figure 15 exemplifies this where the water surface corresponds to the Celtic Straits and the upland surface designates the Camrien Peninsula. For L different land surface regions and W different water surface regions, there will be 3L+4W atomic regions to consider. In the North Atlantis scenario of section 7.1, L=9 and W=10, and so there are 67 atomic regions to consider. Regions formed from these atomic regions can be expressed through the metaphysical operators of section 2.1.2, thus allowing for expressions like (celtic_straits•water + celtic_sea•water).

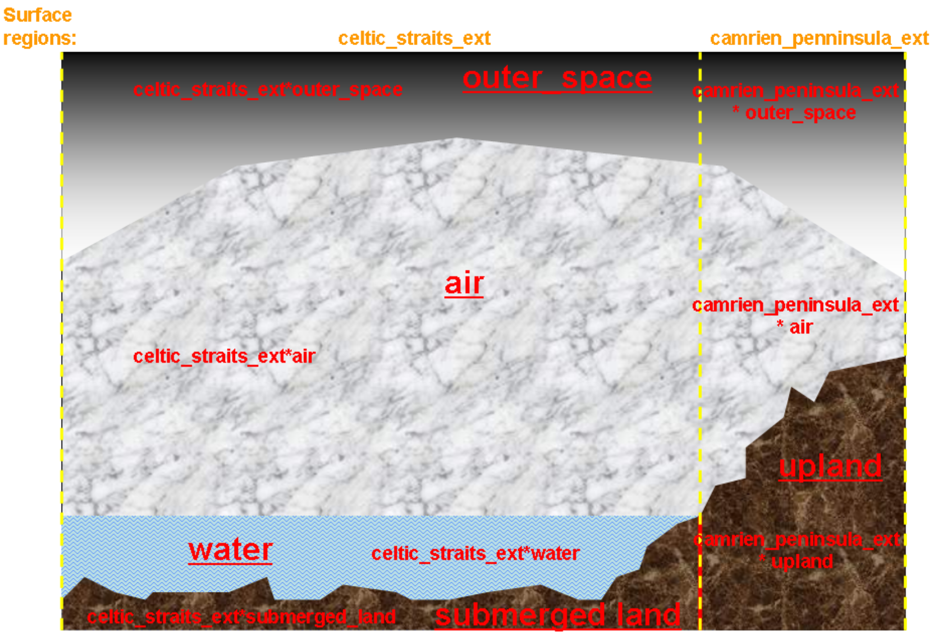

Figure 15: Environmental Regions

These environmental regions can be used to classify objects through their connections to those environmental regions. Figure 16 shows four objects connected to an environmental region canvas.

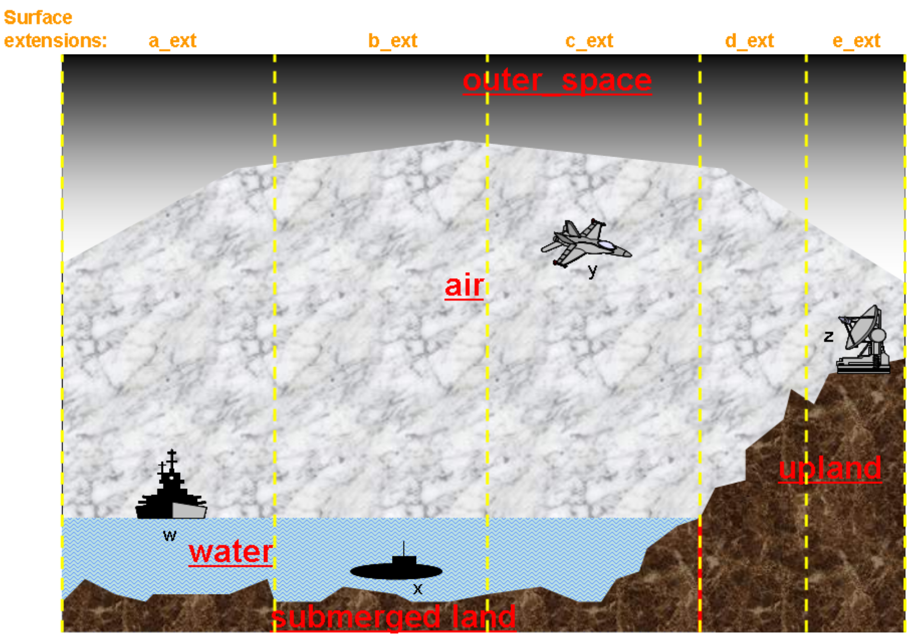

Figure 16: Connections to Environmental Regions

An object could potentially connect with any number of the 3L+4W atomic regions, with there being $2^{(3L+4W)}$ possible connections. In the North Atlantis case of 9 land surface regions and 10 water surface regions, this allows for 2^{67} possible connections! However, most of these require the objects to be disconnected. There are only 13 connected object connections for a given region, which are shown in Figure 17.

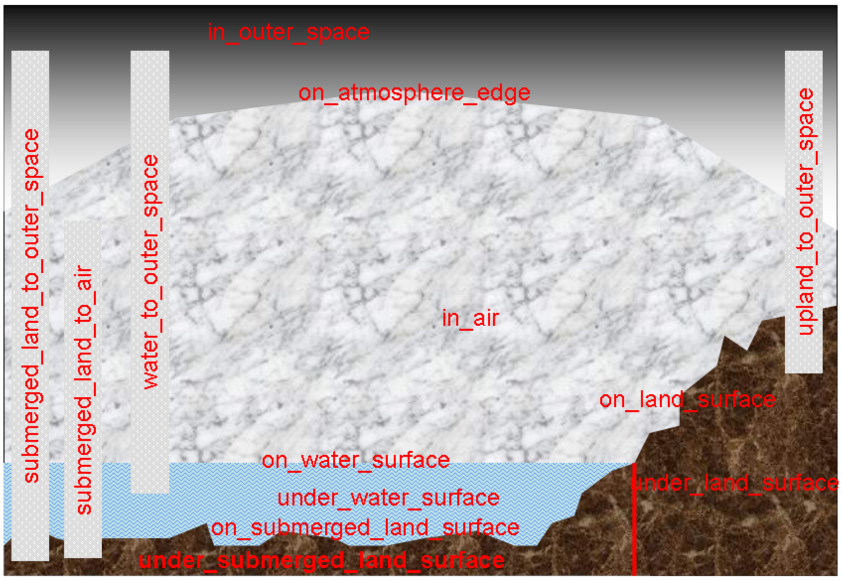

Figure 17: Connected Object Connections to Environmental Regions

This allows objects to be classified according to their environment region connections as demonstrated in Figure 18.

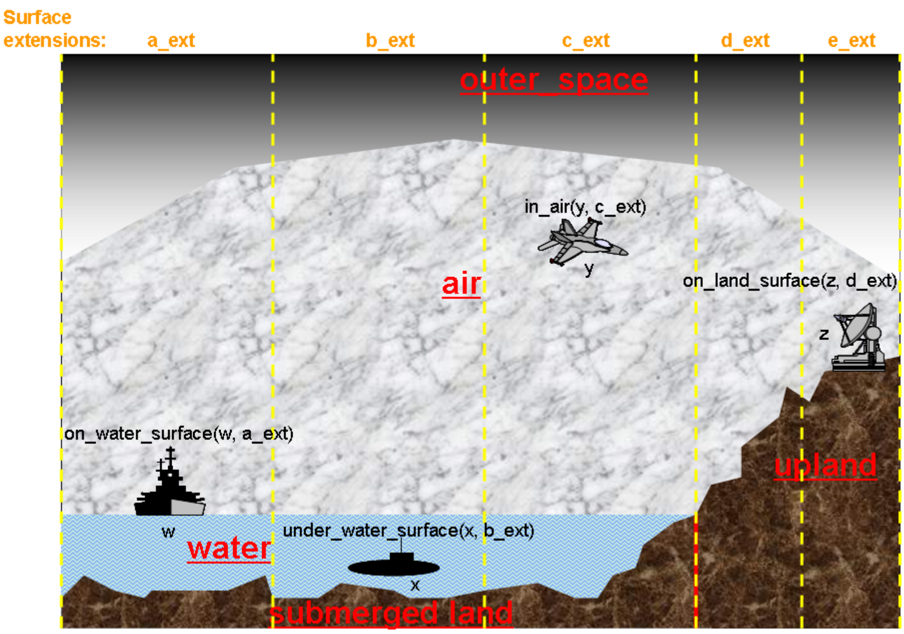

Figure 18: Connected Object Environmental Region Classifications

If object y had straddled the airspace of both surface regions c and d, then this can be expressed by the conjunction **in_air**(y, c_ext) & **in_air**(y, d_ext).

Relation	Type	Primitive	Phrase
submerged_land_to _outer_space(x, r)	relation	N	x ranges from the submerged land below through to the outer space above extended region r
submerged_land_to _air(x, r)	relation	N	x ranges from the submerged land below through to the air space above extended region r
on_submerged_land _surface(x, r)	relation	N	x is on the submerged land surface of extended region r
under_submerged_land _surface(x, r)	relation	N	x is under the submerged land surface of extended region r
water_to_outer _space(x, r)	relation	N	x ranges from in the water through to the air space above extended region r
on_water _surface(x, r)	relation	N	x is on the water surface of extended region r
under_water _surface(x, r)	relation	N	x is under the water surface of extended region r
on_atmosphere _edge(x, r)	relation	N	x is on the edge of the atmosphere over extended region r
in_air(x, r)	relation	N	x is in the air space over extended region r
in_outer_space(x, r)	relation	N	x is in outer space over extended region r
upland_to_outer _space(x, r)	relation	N	x ranges from in the land through to the outer space above extended region r
on_land _surface(x, r)	relation	N	x is on the land surface of extended region r
under_land _surface(x, r)	relation	N	x is under the land surface of extended region r
disconnected _across(x, r)	relation	N	x is disconnected across regions of extended region r
no_known _connections(x, r)	relation	N	x has no known connections with extended region r
environment _region(x, r, α)	relation	N	α (being one of the above descriptions) describes the environment region connection of x with extended region r

Figure 19: Some Environment Region Concepts

The connected object predicates for connections to environment regions have straightforward definitions, with **in_air** outlined below.

in_air(x, a_ext) $=_{df}$
  (**water_surface**(a_ext) &
    connects(x, a_ext•air) &
    ¬**connects**(x, a_ext•water) &
    ¬**connects**(x, a_ext•outer_space) &
    ¬**connects**(x, a_ext•submerged_land)) ∨
  (**land_surface**(a_ext) &
    connects(x, a_ext•air) &
    ¬**connects**(x, a_ext•upland) &
    ¬**connects**(x, a_ext•outer_space)).

3.2 Environmental Measures

Section 2.2.2 introduced the functional type **seconds** for temporal measurement and section 2.3.2 provides the functional type **metres** for spatial measurement. The remaining Système International d'unités (SI units) for physical base types are provided. This includes units for mass, current, temperature, luminosity and substance. x having a temperature of 16°C is formally expressed by **temperature**(x, **kelvins**(16+273.15)).

Relation	Type	Primitive	Phrase
[0, ∞)	constants	Y	tokens for mass in kilograms
[0, ∞)	constants	Y	tokens for current in amperes
[0, ∞)	constants	Y	tokens for temperature in kelvins
[0, ∞)	constants	Y	tokens for luminosity in candelas
[0, ∞)	constants	Y	tokens for substance in moles
{0, 1, 2, …}	constants	Y	tokens for cardinality
kilograms(v)	function	Y	the value v in kilograms
amperes(v)	function	Y	the value v in amperes
kelvins(v)	function	Y	the value v in kelvins
candelas(v)	function	Y	the value v in candelas
moles(v)	function	Y	the value v in moles
number(v)	function	Y	the value v as a natural number
mass(x, m)	relation	Y	the mass of x is m in kilograms
current(x, a)	relation	Y	the current of x is a in amperes
temperature(x, k)	relation	Y	the temperature of x is k in kelvins
luminosity(x, m)	relation	Y	the luminosity of x is c in candelas
substance(x, m)	relation	Y	the amount of substance of x is m in moles
cardinality(P, x, n)	relation	Y	the cardinality of fragments within x that satisfy P(x) is n as a natural number
m + n	function	Y	the addition of compatible measures m and n
m - n	function	Y	the subtraction of compatible measures m and n
m × n	function	Y	the multiplication of compatible measures m and n
m ÷ n	function	Y	the division of compatible measures m and n
m ^ n	function	Y	the exponentiation of compatible measures m and n
m < n	relation	N	m is numerically less than n
m = n	relation	Y	m is numerically equal to n
e	constant	Y	the numerical constant e
π	constant	Y	the numerical constant π

Figure 20: Concepts for Environmental Measure

Finite cardinality is also included to measure the number of things, for example the number of ships in a particular fleet. **number** is used as the value unit. **cardinality** can be defined recursively by

cardinality(P, x, **number**(1)) $=_{df}$ ∃!u (u ≤ x & P(u))

cardinality(P, x, **number**(n+1)) $=_{df}$ ∃u (u ≤ x & P(u)) & **cardinality**(P, x-u, **number**(n))).

A second order logic expression can be avoided if **cardinality_P** is defined for each predicate P of interest.

A geographic information system can be employed to link spatial measures (section 2.3.2) with environmental regions (section 3.1).

3.3 Extent

As environmental information is often presented qualitatively, rather than quantitatively, a framework for dealing with this might be useful. Examples include: “heavy” and “light” in relation to mass; “hot” and “cold” in relation to temperature; “bright” and “dim” in relation to luminosity. To accommodate these concepts, the general concept of extent has recently been considered for Mephisto, in recognition that each of the aforementioned is a qualification of extent in a particular context.

The approach taken derives from Natural Semantic Metalanguage, where the primitives small, big, very and more are proposed. Here their meanings are formalised through the introduction of an **extent** function, akin to the **kilograms**, **amperes**, **kelvins**, **candelas** and **moles** functions of Figure 20, and an **amount** predicate as the counterpart to the **mass**, **current**, **temperature**, **luminosity** and **substance** relations in Figure 20. The outline of a formal theory is provided below merely to explain the framework.

Relation	Type	Primitive	Phrase
small	constant	Y	token for small extent
big	constant	Y	token for big extent
medium	constant	N	token for medium extent
extent(v)	function	Y	the value v as an extent
small(v)	function	Y	the smaller amount of v
medium(v)	function	N	the medium extent of v
big(v)	function	Y	the big extent of v
very(v)	function	Y	the intensified extent of v
amount(x, q)	relation	Y	the amount of x is q as an extent

Figure 21: Concepts for Extent

For something to have an extent it must exist.

$\forall$x ($\exists$q (**amount**(x, **extent**(q))) $\Rightarrow$ **exists**(x)).

Small and big are admitted as extents through the constant symbols small and big.

Something is defined to have a medium extent if it has an extent that is neither small nor big.

amount(x, **extent**(medium)) $=_{\mathrm{df}}$
$\exists$q (**amount**(x, **extent**(q))) & $\neg$**amount**(x, **extent**(small)) &
$\neg$**amount**(x, **extent**(large)).

The unary functions **small** and **big** are also admitted subject to the following.

$\forall$x $\forall$q (**amount**(x, **extent**(**small**(q))) $\Rightarrow$ **amount**(x, q)).
$\forall$x $\forall$q (**amount**(x, **extent**(**big**(q))) $\Rightarrow$ **amount**(x, q)).

amount(x, **extent**(**medium**(q))) $=_{\mathrm{df}}$
$\exists$q (**amount**(x, **extent**(q))) & $\neg$**amount**(x, **extent**(**small**(q))) &
$\neg$**amount**(x, **extent**(**big**(q))).

The function **very** is then defined as follows.

very(small) $=_{df}$ **small**(small).
very(medium) $=_{df}$ **medium**(medium).
very(big) $=_{df}$ **big**(big).
very(**small**(q)) $=_{df}$ **small**(**small**(q)).
very(**medium**(q)) $=_{df}$ **medium**(**medium**(q)).
very(**big**(q)) $=_{df}$ **big**(**big**(q)).

The foregoing allows expressions like **very**(**very**(small)) and allows one to conclude that if x is very, very small, then it is both very small and small i.e.
∀x (**amount**(x, **extent**(**very**(**very**(small)))) ⇒ **amount**(x, **extent**(**very**(small))))
∀x (**amount**(x, **extent**(**very**(**very**(small)))) ⇒ **amount**(x, **extent**(small))).

The relation **more** is then defined by
more(**extent**(medium), **extent**(small)).
more(**extent**(big), **extent**(medium)).
∀q (**more**(**extent**(**medium**(q)), **extent**(**small**(q)))).
∀q (**more**(**extent**(**big**(q)), **extent**(**medium**(q)))).
∀q (¬**more**(**extent**(q), **extent**(q))).
∀p ∀q ∀r ((**more**(**extent**(p), **extent**(q)) & **more**(**extent**(q), **extent**(r)))
⇒ **more**(**extent**(p), **extent**(r))).

The effect of these axioms is illustrated in Figure 22.

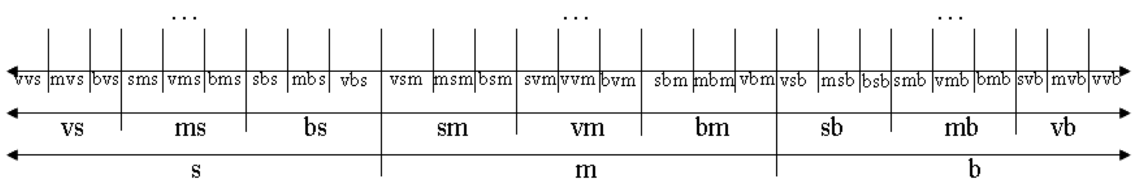

Figure 22: Extent Composition and Ordering

Completeness of the formal theory is the penalty for introducing **extent** as a natural language concession unless quantitative measures are associated with the qualitative extent values. The extent construct is likely to be revisited in future revisions of the Mephisto framework.

4. Functional

4.1 Operational Taxonomy

The Functional Layer identifies parts and the functional roles that they can perform. Consequently it usually includes a taxonomy of operationally focussed equipment, which extends the Environmental Layer taxonomy. Figure 23 provides a very simple illustration with types of radar. The elements of the operational hierarchy tend to be domain specific. Relevant relationships for the relations in Figure 24 are:

$\forall$x (**fps_508**(x) $\Rightarrow$ **long_range_radar**(x)),
$\forall$x (**fps_504**(x) $\Rightarrow$ **short_range_radar**(x)),
$\forall$x (**short_range_radar**(x) $\Rightarrow$ **ground_based_radar**(x)),
$\forall$x (**long_range_radar**(x) $\Rightarrow$ **ground_based_radar**(x)).

Relation	Type	Primitive	Phrase
fps_508(x)	relation	Y	x is an fps_508
fpn_504(x)	relation	Y	x is an fpn_504
short_range_radar(x)	relation	Y	x is a short range radar
long_range_radar(x)	relation	Y	x is a long range radar
ground_based_radar(x)	relation	Y	x is a ground based radar
...			

Figure 23: Operational Taxonomy

4.2 Operational Status

The Functional Layer can describe operational functionality. Operational status predicates include the conventional **operational**, **disrupted**, **neutralised** and **destroyed**. **operating** is the only primitive term required to define these. Disrupted involves an entity with intermittent operational functionality over a period of time. Neutralised involves an entity which can not function operationally for a period. Destroyed involves an entity which can never again function operationally.

Relation	Type	Primitive	Phrase
operating(x)	relation	Y	x is operational
operational(x, t)	relation	N	x is operational for period t
disrupted(x, t)	relation	N	x is disrupted for period t
neutralised(x, t)	relation	N	x is neutralised for period t
destroyed(x)	relation	N	x is destroyed

Figure 24: Operational Status Concepts

Formally,

operational(x, t) $=_{df}$
period(t) & $\forall$p((**period**(p) & p $\leq$ t) $\Rightarrow$ $\exists$s (**operating**(@(x, p, s)))).

disrupted(x, t) $=_{df}$
period(t) & $\exists$p $\exists$s (**period**(p) & p $\leq$ t & **operating**(@(x, p, s)))
& $\exists$p $\exists$s (**period**(p) & p $\leq$ t & $\neg$**operating**(@(x, p, s))).

neutralised(x, t) $=_{df}$
period(t) & $\forall$p $\forall$s ((**period**(p) & p $\leq$ t) $\Rightarrow$ $\neg$**operating**(@(x, p, s)))
& $\exists$p $\exists$s (**period**(p) & **after**(p, t) & **operating**(@(x, p, s))).

destroyed(@(x, t, s)) $=_{df}$
$\forall$p $\forall$m (**after**(p, t) $\Rightarrow$ $\neg$**operating**(@(x, p, m))).

4.3 Operation

The functional level deals with concepts that specify functionality. In the military and national security context, this involves the following relations:

- **senses**;
- **moves**;
- **strikes**;
- **informs**;
- **attached**;
- **transforms**; and
- **interprets**.

senses describes the role of *sensors*; **move** describes *movement*; **strikes** describes the use of *weapons*, **informs** describes *communications*, **attached** describes the attachment of one entity to another, particularly during movement, and so recovers *logistics*; **transforms** describes the ability for something to transform the nature of something else, and so describes *engineering*; and **interprets** describes the propositional *assessment* of a piece of information. Thus the Mephisto contention is that the functional elements of operational military equipment can be captured by these relations. Expressions are the nominalist form of propositions. Expressions are parts of the world that are interpreted propositionally, which might be as diverse as text in a newspaper or beliefs somehow neurophysiologically realised in one's head. **interprets**(x, y, α) means that x associates fragment y in the world with propositional expression α, which is also a fragment of the world, while **about**(α, y, x) holds if interpretation α by x is at least partly about y. **transforms**, **expr** and **interprets** are sufficient as primitives.

Relation	Type	Primitive	Phrase
transforms(z, x, y)	relation	Y	z transforms x into y
expr(α)	relation	Y	α is a propositional expression
interprets(x, y, α)	relation	Y	x interprets y as α
about(α, y, x)	relation	N	propositional expression α is about y according to x
moves(z, x, y)	relation	N	z moves x to y
senses(x, y, z)	relation	N	x senses y as z
informs(x, y, α)	relation	N	x informs y that α
strikes(x, y)	relation	N	x strikes y
attached(x, y)	relation	N	x is attached to y

Figure 25: Operational Concepts

4.4 Capability

It is also important to understand capability in terms of the ability to perform each of the operational relations. The operation predicates are used to describe functional roles *being* performed, such as a radar sensing a target or a missile striking a ship. The capability predicates, by contrast, are used to describe functional roles that *can be* performed, such as the ability for a radar to sense a particular target or the ability of a missile to strike a particular ship. It may be that a missile can strike a particular ship, but for some reason does not (e.g. both belong to the same force). Consequently the following relations are also required:

- **can_sense**;
- **can_move**;
- **can_strike**;
- **can_inform**;
- **can_attach**;
- **can_transform**; and
- **can_interpret**.

This provides a means of viewing military capability functionally rather than from a platform centric perspective, and so aids in the development of a network centric warfare conceptualisation.

Relation	Type	Primitive	Phrase
can_ transform(z, x, y)	relation	Y	z can transform x into y
can_ interpret(x, y, α)	relation	Y	x can interpret y as expression α
can_move(z, x, y)	relation	N	z can move x to y
can_sense(x, y, z)	relation	N	x can sense y as z
can_inform(x, y, α)	relation	N	x can inform y that α
can_strike(x, y)	relation	N	x can strike y
can_attach(x, y)	relation	N	x can_attach to y

Figure 26: Capability Concepts

For example, the sensing capability of the fps_508 long range radar can be expressed by stating that if s is a fps_508 radar at time t and location c, then it can sense a target z at time t as something w if and only if: s is at location c at time t; s is operational at that time t; the target z is at a coordinate with latitude φ, longitude ϕ, and altitude m at time t; the distance from the coordinate c to the coordinate with latitude φ, longitude ϕ, and altitude m is d metres; and the distance d is within the designated 95% confidence range of the fps_508 radar for an altitude of m metres. Formally this is expressed by,

$$
\begin{array}{l}
\forall t\ \forall s\ \forall c\ (\\
(\mathbf{fps\_508}(@(s, t, c)) \Rightarrow \\
\quad \forall z\ \forall \varphi\ \forall \phi\ \forall m\ \forall w\ \forall d\ \forall r\ (\mathbf{can\_sense}(@(s, t, c), @(z, t, \mathbf{coordinate}(\varphi, \phi, m)), w) \Leftrightarrow \\
\quad (\mathbf{at}(s, t, c)\ \&\ \mathbf{operational}(@(s, t, c))\ \&\ \mathbf{at}(z, t, \mathbf{coordinate}(\varphi, \phi, m))\ \& \\
\quad \mathbf{distance}(c, \mathbf{coordinate}(\varphi, \phi, m), \mathbf{metres}(d))\ \& \\
\quad \mathbf{range\_table}(\text{fps\_508}, m, \mathbf{kilometres}(r))\ \&\ d \leq 1000 \times r)))).
\end{array}
$$

where **range_table**(fps_508, m, **kilometres**(r)) identifies the range r (for 0.95 probability of detection) given a target altitude of m e.g. **range_table**(fps_508, 100, **kilometres**(64.6)).

If only atomic formulae are to be queried, then this could be implemented through the following Horn clauses.

can_sense(@(S, T, C), @(Z, T, coordinate(Lat, Long, Alt)), W) if
    fps_508(@(S, T, C)) & at(S, T, C) & operational(@(S, T, C)) &
    at(Z, T, coordinate(Lat, Long, Alt)) &
    distance(C, coordinate(Lat, Long, Alt), metres(Distance)) &
    range_table(fps_508, Alt, kilometres(Range)) & Distance ≤ 1000×Range).

at(S, T, C) if
    tell_can_sense(@(S, T, C), @(Z, T, coordinate(Lat, Long, Alt)), W) &
    tell_fps_508(@(S, T, C)).

operational(@(S, T, C)) if
    tell_can_sense(@(S, T, C), @(Z, T, coordinate(Lat, Long, Alt)), W) &
    tell_fps_508(@(S, T, C)).

at(Z, T, coordinate(Lat, Long, Alt)) if
    tell_can_sense(@(S, T, C), @(Z, T, coordinate(Lat, Long, Alt)), W) &
    tell_fps_508(@(S, T, C)).

Distance ≤ 1000×Range if
    tell_can_sense(@(S, T, C), @(Z, T, coordinate(Lat, Long, Alt)), W) &
    tell_fps_508(@(S, T, C)) &
    distance(C, coordinate(Lat, Long, Alt), metres(Distance)) &
    range_table(fps_508, Alt, kilometres(Range)).

Of course more detailed sensor models can be developed if required.

4.5 Extensions

The aforementioned functional account can be extended to provide greater detail if required. For example, relations can be defined to distinguish between passive and active sensors, as suggested in Figure 27.

Relation	Type	Primitive	Phrase
actively_ senses(x, α)	relation	N	x actively senses α
passively_ senses(x, α)	relation	N	x passively senses α

Figure 27: Extending Concepts

5. Cognitive

5.1 ATTITUDE

The Cognitive Layer currently describes the ATTITUDE cognitive model at an abstract level. The ATTITUDE cognitive model has been implemented as a framework for multi-agent reasoning ([18]). The ATTITUDE cognitive model characterises cognitive individuals through the primitive **cognitive**. Asserting **cognitive**(X) is to assert that X is a cognitive individual.

Relation	Type	Primitive	Phrase
cognitive(X)	relation	Y	X is a cognitive individual
I	function	Y	I provides indexical self reference for a cognitive individual

Figure 28: Cognitive Individual Concepts

5.2 Cognitive Taxonomy

Figure 29 illustrates the ATTITUDE cognitive model. Long-term memory houses cognitive routines that can be selected and executed. The execution of a routine R by cognitive individual X gives rise to changes in awareness, volition, interaction and internal action working memories within X. Awareness includes beliefs, expectations and anticipations. Volition includes independent intentions and potentially nested dependent desires. Intentions therefore signify a greater commitment than desires. Interactions include perceiving the world, effecting outcomes in the world, and the ability to inform other cognitive individuals. The internal mental actions occur when a cognitive individual X has volition to satisfy expression α, identifies routines whose behaviour can achieve α, and performs some of those routines, resulting in changes to working and possibly long-term memory.

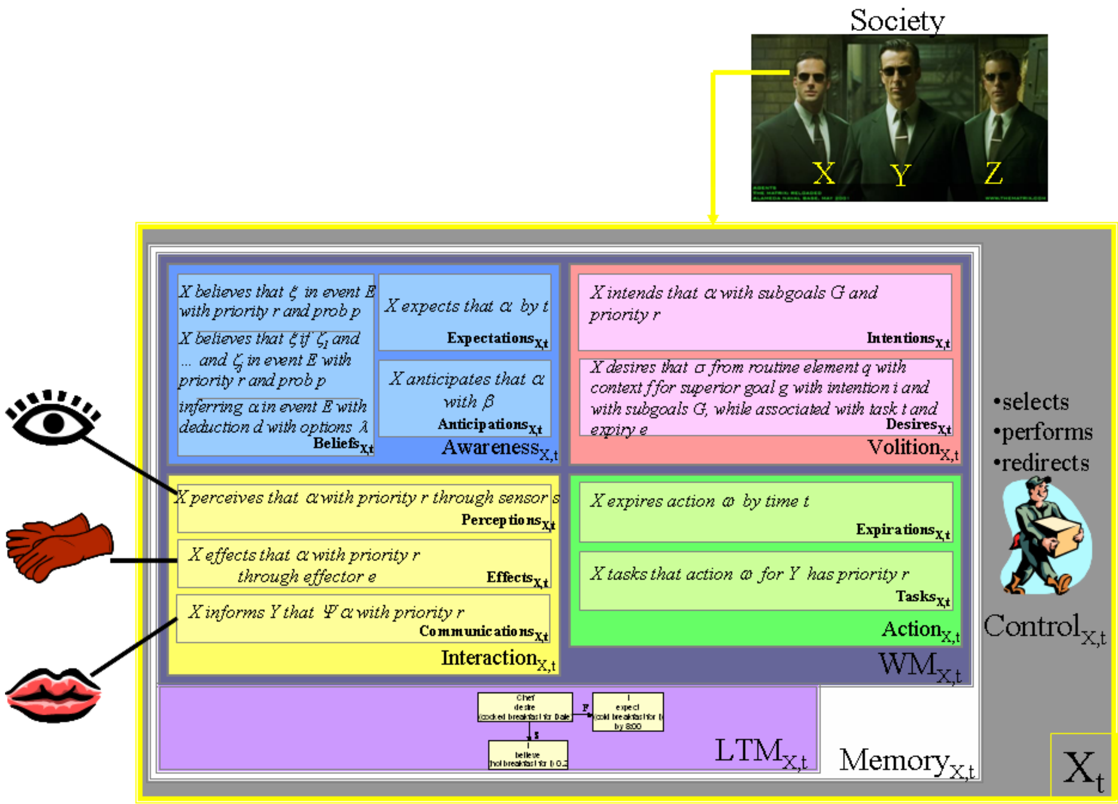

Figure 29: ATTITUDE Cognitive Model

In ATTITUDE, routines employ *propositional attitude instructions* like

I believe operational(ship6),

Fred desire operational(sub4),

with the former resulting in the host agent believing operational(ship6) and with the latter resulting in the host agent requesting agent Fred to desire operational(sub4). In the latter case it becomes apparent that routines can include roles for other (possibly unspecified) cognitive individuals to perform, and so interactions between cognitive individuals' cognitive routines effectively provide social routines.

5.3 Cognitive Routines

As noted, a cognitive individual is taken to possess a collection of cognitive routines, or recipes for mental behaviour, which are capable of achieving certain outcomes. The internal implementation details of ATTITUDE routine execution are largely masked in the Mephisto conceptualisation. **routine**(R) identifies R as a (cognitive) routine, with use of the term "routine" intending to appeal to both "routine" in the sense of "routine behaviour" and "routine" in its Computer Science sense. **can_perform**(X, R) identifies cognitive individual X as having the ability to perform cognitive routine R; **performs**(X, R, ξ) indicates that X performs routine R as behaviour ξ; **succeeds**(ξ) and **fail**(ξ) denote the success or failure respectively of the behaviour ξ; and **achieves**(ξ, α) notes that behaviour ξ achieves the outcome or effect α. To illustrate, the following might be used to classify a C130 pilot.

$$\textbf{c130\_pilot}(X) =_{df} \textbf{cognitive}(X) \;\&\; \textbf{can\_perform}(X, \text{fly\_c130}) \;\&\; \forall a\, \forall \xi\, ((\textbf{c130}(a) \;\&\; \textbf{attached}(X, a) \;\&\; \textbf{performs}(X, \text{fly\_C130}, \xi) \;\&\; \textbf{succeeds}(\xi)) \Rightarrow \textbf{achieves}(\xi, \textbf{flying}(a))).$$

with **flying** subsequently defined as 'self propulsion through the air', expressed formally using metaphysical, environmental and functional primitives.

Within the implemented ATTITUDE model the **approves** and **disapproves** predicates are applied as success and fail constructs to control the execution of cognitive routines. In the Mephisto model **approves** and **disapproves** provide a basis for some absolute value judgements, like good and bad; **succeeds** and **fails** provide a basis for other absolute value judgements, such as true and false; while the **prefer** predicate provides scope for representing relative value judgements. Emotional behaviour by a cognitive individual can be cast in terms of heightened preference for lower level limbic system like routines, including fighting, feeding, fleeing and sexual intercourse.

Relation	Type	Primitive	Phrase
routine(R)	relation	Y	R is a cognitive routine
learns(X, R)	relation	N	cognitive individual X learns routine R
can_perform(X, R)	relation	Y	cognitive individual X can do routine R
performs(X, R, ξ)	relation	Y	X performs R as behaviour ξ
succeeds(ξ)	relation	Y	behaviour ξ succeeds
fails(ξ)	relation	Y	behaviour ξ fails
achieves(ξ, α)	relation	Y	behaviour ξ achieves α
approves(X, α)	relation	Y	cognitive individual X approves of propositional expression outcome α
disapproves(X, α)	relation	Y	cognitive individual X disapproves of propositional expression outcome α
prefers(X, α, β)	relation	N	cognitive individual X prefers that α than β

Figure 30: Cognitive Routine Concepts

5.4 Awareness

The Mephisto model characterises three kinds of awareness of the world by a cognitive individual.

$$\textbf{aware}(X, \alpha) =_{df} \textbf{believes}(X, \alpha) \vee \exists t\, (\textbf{expects}(X, \alpha, t)) \vee \exists \beta\, (\textbf{anticipates}(X, \alpha, \beta)).$$

Note that psychological awareness of α by X does not necessarily mean that α is the case.

The first is belief. **believes**(X, α) is used to stipulate that cognitive individual X believes that α is the case. The expression α can be quite complex. X may in effect support epistemic modus ponens deductions because the following holds for X

$$\forall \alpha\, \forall \beta\, ((\textbf{believes}(X, (\alpha \Rightarrow \beta)) \;\&\; \textbf{believes}(X, \alpha)) \Rightarrow \textbf{believes}(X, \beta)),$$

though most people would fail to meet this criteria. Other inferential styles can also be formulated for a cognitive individual X, including inductive and abductive reasoning, reasoning under uncertainty, *et cetera*, and can even include highly irrational reasoning that might actually be characteristic of X. This is an important point. The Mephisto aim is to provide a **believes** predicate that can be used to model whatever kinds of inferential processes are considered representative of a cognitive individual. In that sense it delivers a methodologically grounded notion of belief that seeks to capture what one thinks an agent *does* do, not an epistemically grounded notion of belief that prescribes what one thinks an agent *should* do according to some epistemic logic.

Expectations and anticipations provide the other two forms of awareness. In ATTITUDE, "X expect α by t" and "X anticipate α with β" are propositional attitude instructions. When executed, X expect α by t suspends routine execution until α is believed, in which case the instruction succeeds, or deadline t has been reached, in which case the instruction fails. When executed, X anticipate α with β monitors incoming beliefs to see if any match α, and if so, then X acquires the intention to achieve β. Mephisto uses **expects**(X, α, t) and **anticipates**(X, α, β) to characterise these mechanisms. Expectations involve a cognitive individual ceasing some activity until a belief matching the expected proposition occurs. Anticipations involve a cognitive individual monitoring new beliefs in case a belief matching the anticipated proposition occurs, in which case it responds by invoking some activity. New beliefs which are neither expected nor anticipated, fail to invoke additional behaviour.

Relation	Type	Primitive	Phrase
expects(X, α, t)	relation	Y	cognitive individual X expects that α before timestamp t
anticipates(X, α, β)	relation	Y	cognitive individual X anticipates that α with β
believes(X, ϕ)	relation	Y	cognitive individual X believes that ϕ
aware(X, α)	relation	N	cognitive individual X is aware that α

Figure 31: Awareness Concepts

5.5 Interaction

Interactions include perceiving the world, effecting outcomes in the world, and the ability to inform other cognitive individuals. Informs can be extended to cognitive individuals from the functional level. Perception can be viewed as interpreted sensation

perceives(X, α) $=_{df}$ $\exists$z (**cognitive** (X) & **senses**(X, y, z) & **interprets**(X, z, α)).

Effecting the world involves the use of effectors or actuators by X. Cognitive individual X effects outcome α, through effector or actuator e, means that e is a fragment of X that transforms some fragment x of the world into y where X interprets y as outcome α.

effects(X, α, e) $=_{df}$ $\exists$x $\exists$y (e $\leq$ X & **transforms**(e, x, y) & **interprets**(X, y, α)).

Note that whilst under this definition cognitive individual X effects outcome α through effector e it does not necessarily mean that another cognitive individual Y will also interpret the transformation as outcome α. That will depend upon how cognitive individual Y perceives the transformation.

Relation	Type	Primitive	Phrase
perceives(X, α)	relation	N	cognitive individual X perceives that α
effects(X, α, e)	relation	N	cognitive individual X effects outcome α through effector e
informs(X, Y, α)	relation	N	cognitive individual X informs cognitive individual Y that α

Figure 32: Interaction Concepts

5.6 Volition

The predicates **wants** and **aware** define generalised volition and awareness respectively, in which the details are suppressed.

$\textbf{wants}(X, \alpha) =_{df} \textbf{intends}(X, \alpha) \vee \textbf{desires}(X, \alpha).$

Relation	Type	Primitive	Phrase
intends(X, α)	relation	Y	cognitive individual X intends that α
desires(X, α)	relation	Y	cognitive individual X desires that α to satisfy an existing intention
wants(X, α)	relation	N	cognitive individual X wants that α
expects(X, α, t)	relation	Y	cognitive individual X expects that α before timestamp t
anticipates(X, α, β)	relation	Y	cognitive individual X anticipates that α with β
believes(X, ϕ)	relation	Y	cognitive individual X believes that ϕ
aware(X, α)	relation	N	cognitive individual X is aware that α
perceives(X, α)	relation	N	cognitive individual X perceives that α
effects(X, α)	relation	Y	cognitive individual X effects so that α
informs(X, Y, α)	relation	N	cognitive individual X informs cognitive individual Y that α

Figure 33: Cognitive Concepts

The ATTITUDE cognitive model has been implemented computationally based on formal denotational semantics. A formal semantic account of the Mephisto Cognitive Layer requires an axiomatic semantic conversion. This will result in axioms like the following:

$$\forall X\ \forall\alpha\ \forall R\ \forall x\ \forall t_1\ \forall s_1\ \forall t_2\ \forall s_2\ ((\textbf{wants}(@(X, t_1, s_1), \alpha)\ \&\ \textbf{can\_perform}(@(X, t_2, s_2), R)\ \&\ \textbf{believes}(@(X, t_1, s_1), (\textbf{performs}(@(X, t_2, s_2), R, \xi) \Rightarrow \textbf{achieves}(\xi, \alpha)))) \Rightarrow \textbf{performs}(@(X, t_2, s_2), R, \alpha)).$$

As an illustration of interaction between the functional and cognitive levels, cognitive individual X treating x as a thermometer measuring y can be expressed by

$$\textbf{thermometer}(@(x, t_1, s_1), @(X, t_2, s_2), @(y, t_1, s_1)) =_{df} \exists z\ (\textbf{senses}(@(x, t_1, s_1), @(y, t_1, s_1), z)\ \&\ \textbf{cognitive}(@(X, t_2, s_2))\ \&\ \textbf{overlaps}(t_2, t_1)\ \&\ \exists k\ (\textbf{perceives}(@(X, t_2, s_2), z, \textbf{temperature}(@(y, t_2, s_2), \textbf{kelvins}(k))))).$$

6. Social

6.1 Groups of Cognitive Individuals

The Mephisto Social Layer is understood in terms of *the flow of intent* between cognitive individuals. As a consequence, the Social Layer almost has no additional primitive terms, and so some extended discussion is offered here to explain how the social constructs can be formed. The term **group** is introduced to characterise groups of cognitive individuals. The fragment of the world Y within any Z that is composed only from fragments of cognitive individuals is given by

$\mathbf{cognitives}(Y, Z) =_{df} \forall X\ (X \leq Y \Leftrightarrow (\mathbf{cognitive}(X)\ \&\ X \leq Z))$.

A group of cognitive individuals is then that fragment of the world that: a) contains at least one cognitive individual; and b) has fragments composed only from cognitive individuals.

$\mathbf{group}(G) =_{df} \exists X\ (\mathbf{cognitive}(X)\ \&\ X \leq G)\ \&\ \forall Y\ (\mathbf{cognitives}(Y, G) \Rightarrow (G - Y) \equiv \bot)$.

Social groups of interest are typically identified by the agreements and conflicts that unite and differentiate them respectively, with biological families being a notable exception. A few representative social groups are listed below in Figure 34. Taxonomies of social groups will also naturally form.

Relation	Type	Primitive	Phrase
group(G)	relation	N	G is a group of cognitive individuals
judiciary(G)	relation	N	group G is a judiciary
government(G)	relation	N	group G is a government
military(G)	relation	N	group G is a military
religion(G)	relation	N	group G is a religion
english_speakers(G)	relation	N	group G contains cognitive individuals who inform through English expressions
…			

Figure 34: Social Groups

6.2 Agreement and Conflict

Agreements are the mechanism by which social cohesion is formed. Following Common Law ([19]), in Mephisto agreements are understood in terms of offer and acceptance. The interest here is not in the law *per se*, but in the naturally occurring social agreements that the law is seeking to represent. An offer involves informing one's own intent for another to that other, while acceptance involves informing compliance to that intent. So

$\mathbf{offers}(@(Y, t, s_1), @(X, t, s_2), \alpha) =_{df}$

$\exists t_2\ \exists s_3\ (\mathbf{before}(t, t_2)\ \&\ \mathbf{intends}(@(Y, t, s_1), \mathbf{intends}(@(X, t_2, s_3), \alpha))\ \&$

$\mathbf{informs}(@(Y, t, s_1), @(X, t, s_2), \mathbf{intends}(@(Y, t, s_1), \mathbf{intends}(@(X, t_2, s_3), \alpha))))$

characterises Y's offer to X for X to satisfy some outcome α, and then

$\mathbf{agrees}(@(X, t, s_1), @(Y, t, s_2), \alpha) =_{df}$

$\exists t_1\ \exists s_3\ \exists s_4\ (\mathbf{before}(t_1, t)\ \&\ \mathbf{offers}(@(Y, t_1, s_3), @(X, t_1, s_4), \alpha)\ \&$

$\mathbf{intends}(@(X, t, s_1), \alpha)\ \&\ \mathbf{informs}(@(X, t, s_1), @(Y, t, s_2), \mathbf{intends}(@(X, t, s_1), \alpha)))$

characterises X's agreement with Y to satisfy α through X's informed acceptance that X intends to satisfy α. Lambert and Scholz ([20]) outline the Legal Agreement Protocol by which such agreements are formed, but these details are again largely masked in the Mephisto framework. **intends** rather than **wants**, is used in the definitions to signify that they relate to volitions of greater commitment.

Conflicts, by contrast, arise when there are mutually exclusive intentions, and so

conflicts(X, Y, α, β) $=_{df}$
  cognitive(X) & **cognitive**(Y) & **expr**(α) & **expr**(β) &
  intends(X, α) & **intends**(Y, β) & $\alpha \Rightarrow \neg\beta$.

Conflicts can arise without either party being aware of the conflict. Conflict resolution strategies, including surrender and war at the extremes, typically occur when the parties in question believe that they are in conflict, whether or not they actually are.

Relation	Type	Primitive	Phrase
conflicts(X, Y, α, β)	relation	N	cognitive individual X intending α is in conflict with cognitive individual Y intending β
offers(X, Y, α)	relation	N	cognitive individual X offers cognitive individual Y to intend that α
agrees(X, Y, α)	relation	N	cognitive individual X agrees to intend that α for cognitive individual Y

Figure 35: Social Agreements

6.3 Alliance

Allies, enemies and neutrals can be defined in terms of the agreement and conflict constructs. X is an ally of Y with respect to issue α if X agrees with Y about α. X is an enemy of Y with respect to issue α if X is in conflict with Y over α. X is neutral toward Y with respect to issue α if X neither agrees nor conflicts with Y over α.

ally(X, Y, α) $=_{df}$ **agrees**(X, Y, α)
enemy(X, Y, β) $=_{df}$ ∃α **conflict**(X, Y, α, β)
neutral(X, Y, α) $=_{df}$
  cognitive(X) & **cognitive**(Y) & **expr**(α) & ¬**ally**(X, Y, α) & ¬**enemy**(X, Y, α).

Relation	Type	Primitive	Phrase
ally(X, Y, α)	relation	N	cognitive individual X is an ally of Y with respect to α
enemy(X, Y, α)	relation	N	cognitive individual X is an enemy of Y with respect to α
neutral(X, Y, α)	relation	N	cognitive individual X is neutral to Y with respect to α

Figure 36: Social Alliance

6.4 Responsibility, Authority and Competency

In Mephisto, responsibility can be understood as commitment to an informed intention.

$\textbf{responsible}(X, Y, \alpha) =_{df}$
$(\textbf{informs}(X, Y, \textbf{intends}(X, \alpha)) \Rightarrow \textbf{intends}(X, \alpha))$.

X has authority over Y with respect to α if whenever X offers Y the opportunity to achieve an outcome β within the scope of α, Y subsequently agrees.

$\textbf{authority}(@(X, t, s_1), @(Y, t, s_2), \alpha) =_{df}$
$\forall\beta\ (\textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \beta)\ \&\ \beta \Rightarrow \alpha) \Rightarrow$
$\exists t_1\ \exists s_3\ \exists s_4\ (\textbf{before}(t, t_1)\ \&\ \textbf{agrees}(@(Y, t_1, s_3), @(X, t_1, s_4), \beta)))$.

This identifies authority from an *a posteriori* standpoint in that it defines what it means for X to actually have authority over Y with respect to α. The term authority is also often used in the sense of presumed authority, however, which can be defined by

$\textbf{presumes\_authority}(@(X, t, s_1), @(Y, t, s_2), \alpha) =_{df}$
$\forall\beta\ (\textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \beta)\ \&\ \beta \Rightarrow \alpha) \Rightarrow$
$\textbf{expects}(@(X, t, s_1),$
$\exists t_1\ \exists s_3\ \exists s_4\ (\textbf{before}(t, t_1)\ \&\ \textbf{agrees}(@(Y, t_1, s_3), @(X, t_1, s_4), \beta))))$.

X has the competency to achieve α if there is a routine R that X can do and whenever R is performed by X, it achieves α.

$\textbf{competency}(X, \alpha) =_{df}$
$\textbf{cognitive}(X)\ \&\ \textbf{expr}(\alpha)\ \&$
$\exists R\ \exists\xi\ (\textbf{routine}(R)\ \&\ \textbf{can\_perform}(X, R)\ \&\ (\textbf{performs}(X, R, \xi) \Rightarrow \textbf{achieves}(\xi, \alpha)))$.

X has the competency to achieve α through routine R if X can do R and whenever R is performed by X, it achieves α.

$\textbf{competency}(X, \alpha, R) =_{df}$
$\textbf{cognitive}(X)\ \&\ \textbf{expr}(\alpha)\ \&\ \textbf{routine}(R)\ \&$
$\exists\xi\ (\textbf{can\_perform}(X, R)\ \&\ (\textbf{performs}(X, R, \xi) \Rightarrow \textbf{achieves}(\xi, \alpha)))$.

Relation	Type	Primitive	Phrase
competency(X, α)	relation	N	cognitive individual X has the competency to achieve outcome α
authority(X, Y, α)	relation	N	cognitive individual X has authority over Y with respect to α
responsible(X, Y, α)	relation	N	cognitive individual X is responsible to cognitive individual Y to achieve outcome α

Figure 37: Competency, Authority and Responsibility Concepts

6.5 Command

Pigeau and McCann ([21]) define command by,

"Command is the creative expression of human will necessary to accomplish the mission",

and associate command and control with competency, authority and responsibility. A formal analysis of command leads to abandonment of the term "creative" as it is too subjective to add any genuine value to the definition. The presumption that command pertains to "human will" is also dropped in Mephisto, where the construct **cognitive** substitutes for "human" while **intends** replaces "will". This deliberately allows command to be generalised to multi-agent systems composed of people, machines, or a combination of the two.

There are several senses of the term "command", there being 2^4 (=16) possible formulations involving competency, authority, responsibility and outcome. Three are defined below.

The first is termed **commands_to_achieve** and allows for expressions like "The Major refused to obey my command." In this instance the commander presumes authority, responsibility and competency, none of which may be the case. Informally it is defined by

commands_to_achieve(X, Y, α) $=_{df}$
  offers(X, Y, α) & **believes**(X, **competency**(Y, α)) &
  believes(X, **responsible**(Y, α)) & **presumes_authority**(X, Y, α).

The second is termed **successfully_commands_to_achieve** and it accommodates expressions like "ADM Nelson is in command of the fleet". Here there is a presumption of competency, but authority and responsibility have been established by agreement, though the intended outcome may not be achieved.

successfully_commands_to_achieve(X, Y, α) $=_{df}$
  offers(X, Y, α) & **believes**(X, **competency**(Y, α)) & **authority**(X, Y, α).

The third is termed **successfully_commands_to_successfully_achieve** and it accommodates expressions like "The GPCAPT commanded the air strike". This involves an authoritative, responsible and competent achievement of the outcome.

successfully_commands_to_successfully_achieve(@(X, t, s_1), @(Y, t, s_2), α) $=_{df}$
  offers(@(X, t, s_1), @(Y, t, s_2), α) & **believes**(X, **competency**(Y, α)) &
  authority(@(X, t, s_1), @(Y, t, s_2), α) &
  $\exists t_1 \exists s_3 \exists R \exists \xi$ (**routine**(R) & **performs**(@(Y, t_1, s_3), R, ξ) & **achieves**(ξ, α)).

Relation	Type	Primitive	Phrase
commands_to_ achieve(X, Y, α)	relation	N	cognitive individual X commands Y to achieve α
successfully_commands_ to_achieve(X, Y, α)	relation	N	cognitive individual X successfully commands Y to achieve α
successfully_commands_ to_successfully_ achieve(X, Y, α)	relation	N	cognitive individual X successfully commands Y to successfully achieve α

Figure 38: Command Concepts

6.6 Control

There are at least three analogous senses of the term "control". The first is termed **controls_to_achieve**. In general control extends beyond command in that the controller disseminates a plan (routine) for achieving intent, and monitors and corrects execution of that plan. A plan is an expression interpreted as a cognitive routine and we recall from section 5.2 that cognitive routines give rise to social routines when the propositional attitude instructions refer to other cognitive individuals that become engaged. The monitoring and correction of plan execution is termed "oversees", and is defined formally as follows

$$
\begin{aligned}
&\textbf{oversees}(@(X, t, s_1), @(Y, t, s_2), \alpha, R, \xi) =_{df} \\
&\quad \exists t_1\, \exists s_3\, (\textbf{before}(t_1, t)\ \&\ \textbf{perceives}(@(X, t_1, s_3), \xi))\ \& \\
&\quad (\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha)) \lor \\
&\quad (\neg\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha))\ \& \\
&\quad\ \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\, \forall s_4\, (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi)))\ \& \\
&\quad\ \textbf{presumes\_authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\, \forall s_4\, (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi))) \\
&\quad\ \exists R_1\, (\textbf{controls\_to\_achieve}(@(X, t, s_1), @(Y, t, s_2), \alpha, R_1)))).
\end{aligned}
$$

controls_to_achieve is then defined by the following, with pairwise recursion between **oversees** and **controls_to_achieve** facilitating periodic correction attempts, if required.

$$
\begin{aligned}
&\textbf{controls\_to\_achieve}(@(X, t, s_1), @(Y, t, s_2), \alpha, R) =_{df} \\
&\quad \textbf{believes}(@(X, t, s_1), \textbf{competency}(@(X, t, s_1), \alpha, R))\ \& \\
&\quad \textbf{believes}(@(X, t, s_1), \textbf{responsible}(@(Y, t, s_1), @(X, t, s_2), \alpha))\ \& \\
&\quad \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\, \exists s_3\, \exists \xi\, (\textbf{before}(t, t_1)\ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi)\ \&\ \textbf{achieves}(\xi, \alpha)))\ \& \\
&\quad \textbf{presumes\_authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\, \exists s_3\, \exists \xi\, (\textbf{before}(t, t_1)\ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi)\ \&\ \textbf{achieves}(\xi, \alpha)))\ \& \\
&\quad \exists t_2\, \exists s_4\, \exists s_5\, \exists R_1\, \exists \xi_1\, (\textbf{before}(t, t_2)\ \&\ \textbf{performs}(@(Y, t_2, s_4), R_1, \xi_1))\ \& \\
&\qquad\qquad\qquad \textbf{oversees}(@(X, t_1, s_5), @(Y, t_2, s_4), \alpha, R_1, \xi_1).
\end{aligned}
$$

Note that the R_1 and ξ_1 performed by Y might not be the R and ξ intended by X, as Y has not necessarily agreed to do so. Technically, the pairwise recursion terminates within the **oversees** predicate with **believes**(@(X, t, s_1), **achieves**(ξ, α)). Presenting these predicates as definitions, rather than more correctly as axioms, allows the coroutining nature of a computational implementation to be more explicit.

The second sense of control is termed **successfully_controls_to_achieve**. This extends **controls_to_achieve** by X having authority over Y.

$$
\begin{aligned}
&\textbf{successfully\_oversees}(@(X, t, s_1), @(Y, t, s_2), \alpha, R, \xi) =_{df} \\
&\quad \exists t_1\, \exists s_3\, (\textbf{before}(t_1, t)\ \&\ \textbf{perceives}(@(X, t_1, s_3), \xi))\ \& \\
&\quad (\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha)) \lor \\
&\quad (\neg\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha))\ \&
\end{aligned}
$$

$$\begin{aligned}
&\quad \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\ \forall s_4\ (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi))) \ \& \\
&\quad \textbf{authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\ \forall s_4\ (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi))) \\
&\quad \exists R_1\ (\textbf{successfully_controls_to_achieve}(@(X, t, s_1), @(Y, t, s_2), \alpha, R_1)))).
\end{aligned}$$

successfully_controls_to_achieve is then defined by the following.

$$\begin{aligned}
&\textbf{successfully_controls_to_achieve}(@(X, t, s_1), @(Y, t, s_2), \alpha, R) =_{df} \\
&\quad \textbf{believes}(@(X, t, s_1), \textbf{competency}(@(X, t, s_1), \alpha, R)) \ \& \\
&\quad \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\ \exists s_3\ \exists \xi\ (\textbf{before}(t, t_1) \ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi) \ \&\ \textbf{achieves}(\xi, \alpha))) \ \& \\
&\quad \textbf{authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\ \exists s_3\ \exists \xi\ (\textbf{before}(t, t_1) \ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi) \ \&\ \textbf{achieves}(\xi, \alpha))) \ \& \\
&\quad \exists t_2\ \exists s_4\ \exists s_5\ \exists R_1\ \exists \xi_1\ (\textbf{before}(t, t_2) \ \&\ \textbf{performs}(@(Y, t_2, s_4), R_1, \xi_1)) \ \& \\
&\qquad\qquad\qquad \textbf{successfully_oversees}(@(X, t_1, s_5), @(Y, t_2, s_4), \alpha, R_1, \xi_1).
\end{aligned}$$

The third is termed **successfully_controls_to_successfully_achieve**. This extends **successfully_controls_to_achieve** by having the outcome achieved.

$$\begin{aligned}
&\textbf{successfully_oversees_outcome}(@(X, t, s_1), @(Y, t, s_2), \alpha, R, \xi) =_{df} \\
&\quad \exists t_1\ \exists s_3\ (\textbf{before}(t_1, t) \ \&\ \textbf{perceives}(@(X, t_1, s_3), \xi)) \ \& \\
&\quad ((\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha)) \ \&\ \textbf{achieves}(\xi, \alpha)) \vee \\
&\quad (\neg\textbf{believes}(@(X, t, s_1), \textbf{achieves}(\xi, \alpha)) \ \& \\
&\quad \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\ \forall s_4\ (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi))) \ \& \\
&\quad \textbf{authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \forall t_2\ \forall s_4\ (\textbf{before}(t, t_2) \Rightarrow \neg\textbf{performs}(@(Y, t_2, s_4), R, \xi))) \\
&\quad \exists R_1\ (\textbf{successfully_controls_to_successfully_achieve}(@(X, t, s_1), \\
&\qquad\qquad\qquad\qquad\qquad @(Y, t, s_2), \alpha, R_1)))).
\end{aligned}$$

successfully_controls_to_successfully_achieve is then defined by the following.

$$\begin{aligned}
&\textbf{successfully_controls_to_ successfully_achieve}(@(X, t, s_1), @(Y, t, s_2), \alpha, R) =_{df} \\
&\quad \textbf{believes}(@(X, t, s_1), \textbf{competency}(@(X, t, s_1), \alpha, R)) \ \& \\
&\quad \textbf{offers}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\ \exists s_3\ \exists \xi\ (\textbf{before}(t, t_1) \ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi) \ \&\ \textbf{achieves}(\xi, \alpha))) \ \& \\
&\quad \textbf{authority}(@(X, t, s_1), @(Y, t, s_2), \\
&\qquad\quad \exists t_1\ \exists s_3\ \exists \xi\ (\textbf{before}(t, t_1) \ \&\ \textbf{performs}(@(Y, t_1, s_3), R, \xi) \ \&\ \textbf{achieves}(\xi, \alpha))) \ \& \\
&\quad \exists t_2\ \exists s_4\ \exists s_5\ \exists R_1\ \exists \xi_1\ (\textbf{before}(t, t_2) \ \&\ \textbf{performs}(@(Y, t_2, s_4), R_1, \xi_1)) \ \& \\
&\qquad\qquad\qquad \textbf{successfully_oversees_outcome}(@(X, t_1, s_5), @(Y, t_2, s_4), \alpha, R_1, \xi_1).
\end{aligned}$$

Relation	Type	Primitive	Phrase
controls(X, Y, α, R)	relation	N	cognitive individual X controls Y to achieve α through routine R
controls_to_ achieve(X, Y, α)	relation	N	cognitive individual X commands Y to achieve α
successfully_ controls(X, Y, α, R)	relation	N	cognitive individual X successfully controls Y to achieve α through routine R
successfully_controls_ to_achieve(X, Y, α)	relation	N	cognitive individual X successfully controls Y to achieve α
successfully_controls_ success(X, Y, α, R)	relation	N	cognitive individual X successfully controls Y to successfully achieve α through routine R
successfully_controls_ to_successfully_ achieve(X, Y, α)	relation	N	cognitive individual X successfully controls Y to successfully achieve α

Figure 39: Control Concepts

6.7 Agency

A noticeable characteristic of the foregoing definitions is that they apply between cognitive individuals. Agreements between cognitive individuals extend to agreements between groups through the Common Law principle of agency ([19]). Agency allows a cognitive individual, termed the principal, to form agreements with a second cognitive individual, termed the agent, so that the agent can subsequently form agreements with third parties on behalf of the principal. Agency extends the concept of agreement beyond immediate interactions between cognitive individuals. So the concept of agreement introduced in section 6.2 is extended to include agency

$$\begin{aligned}&\mathbf{agrees}(@(X, t, s_1), @(Y, t, s_2), \alpha) =_{df}\\&\quad \exists t_1\, \exists s_3\, \exists s_4\, (\mathbf{before}(t_1, t)\ \&\ \mathbf{offers}(@(Y, t_1, s_3), @(X, t_1, s_4), \alpha)\ \&\\&\quad \mathbf{intends}(@(X, t, s_1), \alpha)\ \&\ \mathbf{informs}(@(X, t, s_1), @(Y, t, s_2), \mathbf{intends}(@(X, t, s_1), \alpha))) \vee\\&\quad \exists Z\, \exists s_3\, (\mathbf{agent\_for}(@(Z, t, s_3), @(X, t, s_1), @(Y, t, s_2), \alpha)).\end{aligned}$$

Agency is then defined by

$$\begin{aligned}&\mathbf{agent\_for}(@(Z, t, s_1), @(X, t, s_2), @(Y, t, s_3), \alpha) =_{df}\\&\quad \exists t_1\, \exists s_4\, \exists s_5\, (\mathbf{before}(t_1, t)\ \&\\&\qquad\qquad \mathbf{agrees}(@(X, t_1, s_4), @(Z, t_1, s_5),\\&\qquad\qquad\quad \mathbf{agrees}(@(Z, t, s_1), @(Y, t, s_3), \mathbf{agrees}(@(X, t, s_2), @(Y, t, s_3), \alpha)))).\end{aligned}$$

Thus agreements formed by the agent Z with third party Y to achieve α on behalf of principal X are deemed to be agreements between X and Y to achieve α.

Agency agreements allow a judge to act on behalf of a judiciary in certain respects, a prime minister or general public servant to act on behalf of a government in certain respects, *et cetera*. This allows agency to be defined for groups of cognitive individuals.

$$\begin{aligned}&\mathbf{agent\_for}(Z, G, \alpha) =_{df}\\&\quad \mathbf{group}(G)\ \&\ \forall X\, ((\mathbf{cognitive}(X)\ \&\ X \le G) \Rightarrow \exists Y\, (\mathbf{agent\_for}(Z, X, Y, \alpha))).\end{aligned}$$

Agency also provides a means of classifying groups.

The Mephisto Social Layer is therefore characterised in terms of social consequences based on cognitive individuals. Sociology, by contrast, tends to focus more on group interactions independently of the cognitive individuals involved. Mephisto could be expanded to cater for this.

6.8 Possession and Ownership

Possession is contextual control over something by a cognitive individual. X possesses x relative to context γ if whenever X intends an outcome α about x which is within the scope of γ, then α eventuates. Formally,

$\mathbf{possesses}(X, x, \gamma) =_{df}$
$\forall\alpha\ ((\mathbf{intends}(X, \alpha)\ \&\ (\alpha \Rightarrow \gamma)\ \&\ \mathbf{about}(\alpha, x, X)) \Rightarrow \alpha).$

To illustrate the role of agency, ownership is defined as the legal sanctioning of possession.

$\mathbf{owns}(X, x, G) =_{df}$
$(\mathbf{cognitive}(X)\ \&\ \mathbf{judiciary}(G)\ \&$
$\exists Y\ (\mathbf{agent\_for}(Y, G, \mathbf{agrees}(Y, X, \mathbf{possesses}(X, x, \gamma))).$

Possession without ownership relative to judiciary G is then defined by

$$\mathbf{possesses}(X, x, \gamma)\ \&\ \neg\mathbf{owns}(X, x, G),$$

while illegal possession relative to judiciary G is defined by

$$\mathbf{possesses}(X, x, \gamma)\ \&\ \mathbf{owns}(Y, x, G)\ \&\ \neg\mathbf{agrees}(Y, X, \mathbf{possesses}(X, x, \gamma)).$$

Relation	Type	Primitive	Phrase
possesses(X, x, γ)	relation	N	cognitive individual X possesses x relative to context γ
agent_for(Z, X, Y, a)	relation	N	cognitive individual Z is an agent for principal X with third party Y to achieve outcome α
owns(X, x, G)	relation	N	cognitive individual X owns x with respect to judiciary G

Figure 40: Agency Concepts

6.9 Social Measures

Some basic social measures can also be defined. The population of a social group is simply a cardinality measure of its cognitive individuals.

$\mathbf{population}(G, \mathbf{number}(n)) =_{df} \mathbf{group}(G)\ \&\ \mathbf{cardinality}(\mathbf{cognitive}, G, \mathbf{number}(n)).$

Economies revolve around money as a medium for exchange. Just as the SI units have concepts like mass and distance that are valued in terms of the units kilograms and metres respectively, there is also money that can be valued in terms of (US) dollars if we take that as the standardised currency. If the exchange rate at time t is 1AUD = 0.8527USD, then the value of x, being 25AUD, at time t is represented by $\mathbf{money}(x \bullet t, \mathbf{dollars}(25 \times 0.8527))$. Social agreements become economic agreements when there is a change in the possession of money in exchange for achievement of an outcome.

$$\begin{aligned}
&\textbf{economically_agrees}(@(X, t, s_1), @(Y, t, s_2), \alpha, J, \textbf{dollars}(d)) =_{df} \\
&\quad \textbf{judiciary}(J) \mathbin{\&} \textbf{agrees}(@(X, t, s_1), @(Y, t, s_2), \\
&\quad (\alpha \Leftrightarrow \\
&\quad \exists t_1 \, \exists s_3 \, \exists s_4 \, (\textbf{before}(t, t_1) \mathbin{\&} \exists m \, (\textbf{owns}(@(Y, t, s_2), J, m) \mathbin{\&} \\
&\qquad\qquad \neg\textbf{owns}(@(Y, t_1, s_3), J, m) \mathbin{\&} \textbf{owns}(@(X, t_1, s_4), J, m) \mathbin{\&} \\
&\qquad\qquad \textbf{money}(m \bullet t_1, \textbf{dollars}(d)))))).
\end{aligned}$$

Relation	Type	Primitive	Phrase
$[0, \infty)$	constants	Y	tokens for population value in natural numbers
$[0, \infty)$	constants	Y	tokens for value in dollars
dollars(v)	function	Y	the value v in dollars
population(G, n)	relation	N	the population size of group G is n as a natural number
money(m, d)	relation	Y	the monetary value of m is d in US dollars
economically_ agrees(X, Y, α, J, d)	relation	N	cognitive individual X agrees to intend that α for cognitive individual Y and that d dollars will be legally passed to Y when α has been achieved

Figure 41: Social Measures

7. Examples

7.1 Atlantis Countries

The examples offered in sections 7.1, 7.2 and 7.3 highlight the prescriptive and reductionist nature of the Mephisto approach.

Consider the following information from the North Atlantis scenario ([22]).

> Atlantis is a continent located in the North Atlantic Ocean, between Europe and Greenland. It is shown in Figure 42. Atlantis is composed of six countries: Blueland, Orangeland, Redland, Brownland, Whiteland and Greyland.

Figure 42: Geopolitical Context

So Atlantis is composed of the 6 national regions including Blueland, Redland, Orangeland, Brownland, Greyland, Whiteland and associated water regions. Representing this involves the following three tasks.

1. The compositional structure of each of these regions is identified.
2. The connections between these regions are identified.

3. Geographical measures are introduced through the import of a geographic information system, which uses regional polygons for all the basic regions.

Only the first of these is discussed here.

The vertical extensions of surface names are used to generate the atomic regions. x_ext is used to denoted the vertical extension of surface x. The following are extensions of land surfaces:

> orangeland_land_ext, whiteland_land_ext, redland_land_ext, brownland_land_ext, greyland_land_ext, blueland_mainland_ext, camrien_peninsula_ext, north_celtic_peninsula_ext, manghalour_peninsula_ext.

Thus 'orangeland_land_ext' refers to Orangeland's land and the air space and outer space above it. The following are extensions of water surfaces:

> atlantic_ocean_ext, brown_grey_straits_ext•brownland_region, brown_grey_straits_ext•greyland_region, blueland_region•celtic_sea_ext, celtic_sea_ext•redland_region, brownland_region•celtic_sea_ext, celtic_straits_ext, north_sea_ext, rockall_sea_ext, whiteland_channel_ext.

Thus 'atlantic_ocean_ext' refers to the submerged land below the Atlantic Ocean, the Atlantic Ocean water, and the air space and outer space above the Atlantic Ocean.

The South Celtic Peninsula is also known as the Camrien Peninsula. Therefore,

camrien_peninsula_ext•upland ≡ south_celtic_peninsula_ext•upland.
air•camrien_peninsula_ext ≡ air•south_celtic_peninsula_ext.
camrien_peninsula_ext•outer_space ≡ outer_space•south_celtic_peninsula_ext.

The Orangeland and Whiteland regions are defined by their land extensions.

orangeland_land_ext ≡ orangeland_region.
whiteland_land_ext ≡ whiteland_region.

The remaining compositional structure can be identified through the fragment predicate. A presumption of completeness is presumed when doing this, for example, if $x \leq z$ and $y \leq z$ are only presented here then it is assumed here that $z \equiv x + y$.

The vertical extension of Orangeland's surface includes the upland, air space and outer space regions.

orangeland_land_ext•upland ≤ orangeland_land_ext.
air•orangeland_land_ext ≤ orangeland_land_ext.
orangeland_land_ext•outer_space ≤ orangeland_land_ext.

The vertical extension of Whiteland's surface includes the upland, air space and outer space regions.

upland•whiteland_land_ext ≤ whiteland_land_ext.
air•whiteland_land_ext ≤ whiteland_land_ext.
outer_space•whiteland_land_ext ≤ whiteland_land_ext.

The Celtic Sea is territorially divided between the three countries Blueland, Redland and Brownland.

blueland_region•celtic_sea_ext•submerged_land ≤
blueland_region•celtic_sea_ext.
blueland_region•celtic_sea_ext•water ≤ blueland_region•celtic_sea_ext.
air•blueland_region•celtic_sea_ext ≤ blueland_region•celtic_sea_ext.
blueland_region•celtic_sea_ext•outer_space ≤ blueland_region•celtic_sea_ext.
celtic_sea_ext•redland_region•submerged_land ≤ celtic_sea_ext•redland_region.
celtic_sea_ext•redland_region•water ≤ celtic_sea_ext•redland_region.
air•celtic_sea_ext•redland_region ≤ celtic_sea_ext•redland_region.
celtic_sea_ext•outer_space•redland_region ≤ celtic_sea_ext•redland_region.
brownland_region•celtic_sea_ext•submerged_land ≤
brownland_region•celtic_sea_ext.
brownland_region•celtic_sea_ext•water ≤ brownland_region•celtic_sea_ext.
air•brownland_region•celtic_sea_ext ≤ brownland_region•celtic_sea_ext.
brownland_region•celtic_sea_ext•outer_space ≤ brownland_region•celtic_sea_ext.
blueland_region•celtic_sea_ext ≤ celtic_sea_ext.
celtic_sea_ext•redland_region ≤ celtic_sea_ext.
brownland_region•celtic_sea_ext ≤ celtic_sea_ext.

The Brown Grey Straits is territorially divided between Brownland and Greyland.

brown_grey_straits_ext•brownland_region•submerged_land ≤
brown_grey_straits_ext•brownland_region.
brown_grey_straits_ext•brownland_region•water ≤
brown_grey_straits_ext•brownland_region.
air•brown_grey_straits_ext•brownland_region ≤
brown_grey_straits_ext•brownland_region.
brown_grey_straits_ext•brownland_region•outer_space ≤
brown_grey_straits_ext•brownland_region.
brown_grey_straits_ext•greyland_region•submerged_land ≤
brown_grey_straits_ext•greyland_region.
brown_grey_straits_ext•greyland_region•water ≤
brown_grey_straits_ext•greyland_region.
air•brown_grey_straits_ext•greyland_region ≤
brown_grey_straits_ext•greyland_region.
brown_grey_straits_ext•greyland_region•outer_space ≤
brown_grey_straits_ext•greyland_region.
brown_grey_straits_ext•brownland_region ≤
brown_grey_straits_ext.
brown_grey_straits_ext•greyland_region ≤
brown_grey_straits_ext.

The Redland territory comprises Redland's land and its portion of the Celtic Sea, with the corresponding airspaces and submerged land.

redland_land_ext•upland ≤ redland_land_ext.
air•redland_land_ext ≤ redland_land_ext.

outer_space•redland_land_ext ≤ redland_land_ext.
celtic_sea_ext•redland_region ≤ redland_region.
redland_land_ext ≤ redland_region.

The Greyland region comprises Greyland's land extension and its extension of the Brown Grey Straits.

greyland_land_ext•upland ≤ greyland_land_ext.
air•greyland_land_ext ≤ greyland_land_ext.
greyland_land_ext•outer_space ≤ greyland_land_ext.
brown_grey_straits_ext•greyland_region ≤ greyland_region.
greyland_land_ext ≤ greyland_region.

The Brownland region comprises Brownland's land extension, its extension of the Brown Grey Straits, and its extension of the Celtic Sea.

brownland_land_ext•upland ≤ brownland_land_ext.
air•brownland_land_ext ≤ brownland_land_ext.
brownland_land_ext•outer_space ≤ brownland_land_ext.
brownland_region•celtic_sea_ext ≤ brownland_region.
brown_grey_straits_ext•brownland_region ≤ brownland_region.
brownland_land_ext ≤ brownland_region.

The Blueland region comprises Blueland's land extension, the Celtic Straits extension, and its extension of the Celtic Sea. Blueland's land extension consists of the Blueland mainland extension, the Manghalour Peninsula extension, the North Celtic Peninsula extension and the Camrien Peninsula extension.

blueland_mainland_ext•upland ≤ blueland_mainland_ext.
air•blueland_mainland_ext ≤ blueland_mainland_ext.
blueland_mainland_ext•outer_space ≤ blueland_mainland_ext.
manghalour_peninsula_ext•upland ≤ manghalour_peninsula_ext.
air•manghalour_peninsula_ext ≤ manghalour_peninsula_ext.
manghalour_peninsula_ext•outer_space ≤ manghalour_peninsula_ext.
north_celtic_peninsula_ext•upland ≤ north_celtic_peninsula_ext.
air•north_celtic_peninsula_ext ≤ north_celtic_peninsula_ext.
north_celtic_peninsula_ext•outer_space ≤ north_celtic_peninsula_ext.
camrien_peninsula_ext•upland ≤ camrien_peninsula_ext.
air•camrien_peninsula_ext ≤ camrien_peninsula_ext.
camrien_peninsula_ext•outer_space ≤ camrien_peninsula_ext.
celtic_straits_ext•submerged_land ≤ celtic_straits_ext.
celtic_straits_ext•water ≤ celtic_straits_ext.
air•celtic_straits_ext ≤ celtic_straits_ext.
celtic_straits_ext•outer_space ≤ celtic_straits_ext.
celtic_straits_ext ≤ blueland_region.
blueland_region•celtic_sea_ext ≤ blueland_region.
blueland_mainland_ext ≤ blueland_region.
manghalour_peninsula_ext ≤ blueland_region.

north_celtic_peninsula_ext ≤ blueland_region.
camrien_peninsula_ext ≤ blueland_region.

The remaining water surfaces are: the Atlantic Ocean, the North Sea, the Rockall Sea and the Whiteland Channel.

atlantic_ocean_ext•submerged_land ≤ atlantic_ocean_ext.
atlantic_ocean_ext•water ≤ atlantic_ocean_ext.
air•atlantic_ocean_ext ≤ atlantic_ocean_ext.
atlantic_ocean_ext•outer_space ≤ atlantic_ocean_ext.
north_sea_ext•submerged_land ≤ north_sea_ext.
north_sea_ext•water ≤ north_sea_ext.
air•north_sea_ext ≤ north_sea_ext.
north_sea_ext•outer_space ≤ north_sea_ext.
rockall_sea_ext•submerged_land ≤ rockall_sea_ext.
rockall_sea_ext•water ≤ rockall_sea_ext.
air•rockall_sea_ext ≤ rockall_sea_ext.
outer_space•rockall_sea_ext ≤ rockall_sea_ext.
submerged_land•whiteland_channel_ext ≤ whiteland_channel_ext.
water•whiteland_channel_ext ≤ whiteland_channel_ext.
air•whiteland_channel_ext ≤ whiteland_channel_ext.
outer_space•whiteland_channel_ext ≤ whiteland_channel_ext.

Upland is composed of the uplands of each of the surface land extensions.

orangeland_land_ext•upland ≤ upland.
upland•whiteland_land_ext ≤ upland.
redland_land_ext•upland ≤ upland.
brownland_land_ext•upland ≤ upland.
greyland_land_ext•upland ≤ upland.
blueland_mainland_ext•upland ≤ upland.
camrien_peninsula_ext•upland ≤ upland.
north_celtic_peninsula_ext•upland ≤ upland.
manghalour_peninsula_ext•upland ≤ upland.

Submerged land is composed of the submerged lands of each of the water surface extensions.

atlantic_ocean_ext•submerged_land ≤ submerged_land.
brown_grey_straits_ext•brownland_region•submerged_land ≤ submerged_land.
brown_grey_straits_ext•greyland_region•submerged_land ≤ submerged_land.
blueland_region•celtic_sea_ext•submerged_land ≤ submerged_land.
celtic_sea_ext•redland_region•submerged_land ≤ submerged_land.
brownland_region•celtic_sea_ext•submerged_land ≤ submerged_land.
celtic_straits_ext•submerged_land ≤ submerged_land.
north_sea_ext•submerged_land ≤ submerged_land.
rockall_sea_ext•submerged_land ≤ submerged_land.
submerged_land•whiteland_channel_ext ≤ submerged_land.

Water is composed of the water regions of each of the water surface extensions.

atlantic_ocean_ext•water ≤ water.
brown_grey_straits_ext•brownland_region•water ≤ water.
brown_grey_straits_ext•greyland_region•water ≤ water.
blueland_region•celtic_sea_ext•water ≤ water.
celtic_sea_ext•redland_region•water ≤ water.
brownland_region•celtic_sea_ext•water ≤ water.
celtic_straits_ext•water ≤ water.
north_sea_ext•water ≤ water.
rockall_sea_ext•water ≤ water.
water•whiteland_channel_ext ≤ water.

Air is composed of the air above the land surfaces together with the air above the water surfaces.

air•orangeland_land_ext ≤ air.
air•whiteland_land_ext ≤ air.
air•redland_land_ext ≤ air.
air•brownland_land_ext ≤ air.
air•greyland_land_ext ≤ air.
air•blueland_mainland_ext ≤ air.
air•camrien_peninsula_ext ≤ air.
air•north_celtic_peninsula_ext ≤ air.
air•manghalour_peninsula_ext ≤ air.
air•atlantic_ocean_ext ≤ air.
air•brown_grey_straits_ext•brownland_region ≤ air.
air•brown_grey_straits_ext•greyland_region ≤ air.
air•blueland_region•celtic_sea_ext ≤ air.
air•celtic_sea_ext•redland_region ≤ air.
air•brownland_region•celtic_sea_ext ≤ air.
air•celtic_straits_ext ≤ air.
air•north_sea_ext ≤ air.
air•rockall_sea_ext ≤ air.
air•whiteland_channel_ext ≤ air.

Outer space is composed of the outer space above the land surfaces together with the air above the water surfaces.

orangeland_land_ext•outer_space ≤ outer_space.
outer_space•whiteland_land_ext ≤ outer_space.
outer_space•redland_land_ext ≤ outer_space.
brownland_land_ext•outer_space ≤ outer_space.
greyland_land_ext•outer_space ≤ outer_space.
blueland_mainland_ext•outer_space ≤ outer_space.
camrien_peninsula_ext•outer_space ≤ outer_space.
north_celtic_peninsula_ext•outer_space ≤ outer_space.
manghalour_peninsula_ext•outer_space ≤ outer_space.

atlantic_ocean_ext•outer_space ≤ outer_space.
brown_grey_straits_ext•brownland_region•outer_space ≤ outer_space.
brown_grey_straits_ext•greyland_region•outer_space ≤ outer_space.
blueland_region•celtic_sea_ext•outer_space ≤ outer_space.
celtic_sea_ext•outer_space•redland_region ≤ outer_space.
brownland_region•celtic_sea_ext•outer_space ≤ outer_space.
celtic_straits_ext•outer_space ≤ outer_space.
north_sea_ext•outer_space ≤ outer_space.
outer_space•rockall_sea_ext ≤ outer_space.
outer_space•whiteland_channel_ext ≤ outer_space.

The groups and ownership apportioning can then be defined as follows.
group(united_nations).
group(blueland_nation).
group(whiteland_nation).
group(redland_nation).
group(brownland_nation).
group(greyland_nation).
group(orangeland_nation).
owns(blueland_nation, blueland_region, united_nations).
owns(redland_nation, redland_region, united_nations).
owns(whiteland_nation, whiteland_region, united_nations).
owns(brownland_nation, brownland_region, united_nations).
owns(greyland_nation, greyland_region, united_nations).
owns(orangeland_nation, orangeland_region, united_nations).

7.2 Manghalour Peninsula Conflict

The previous section conceptualises the provided Atlantis country information using the Mephisto constructs. The North Atlantis scenario also includes the following information ([22]),

> One dispute concerns the historic claim by Orangeland over the Manghalour Peninsula, which has changed hands several times over the past centuries. Orangeland had coveted that prosperous region for a long time before to invade it. Orangeland's president has exploited that national feeling in order to divert population attention away from the internal social and economic problems.

The changing ownership can be expressed using Mephisto constructs in the following way, using 3 centuries.

∃t_1 ∃t_2 ∃t_3 ∃t_4 ((**before**(t_1, t_2) v **meets**(t_1, t_2)) & (**before**(t_2, t_3) v **meets**(t_2, t_3)) &
(**before**(t_3, t_4) v **meets**(t_3, t_4)) &
owns(orangeland_nation • t_1, manghalour_peninsula_ext • t_1, united_nations • t_1) &
owns(blueland_nation • t_2, manghalour_peninsula_ext • t_2, united_nations • t_2) &
owns(orangeland_nation • t_3, manghalour_peninsula_ext • t_3, united_nations • t_3) &
owns(blueland_nation • t_4, manghalour_peninsula_ext • t_4, united_nations • t_4) &
∃s ∃f ∃d ∃h ∃m ∃c (**start**(**timestamp**(s), t_1) & **finish**(t_4, **timestamp**(f)) &

$\mathbf{subtract\_time}(\mathbf{timestamp}(f), \mathbf{timestamp}(s), \mathbf{timeperiod}(d, h, m, c))$ & $d > 109500)$

The president of Orangeland is defined as follows.

$$
\begin{aligned}
& Z \equiv \mathbf{president}(\text{orangeland\_nation}) =_{df} \\
& \quad \mathbf{cognitive}(Z) \ \& \\
& \quad \forall X\ \forall G\ \forall \alpha\ ((\mathbf{cognitive}(X)\ \&\ \mathbf{government}(G)\ \&\ G \le \text{orangeland\_nation}\ \&\ X \le G\ \& \\
& \qquad\qquad \forall Y\ (\mathbf{cognitive}(Y)\ \&\ Y \le G\ \&\ \mathbf{about}(\alpha, Y, Z))) \Rightarrow \mathbf{authority}(Z, Y, \alpha)).
\end{aligned}
$$

The Orangeland leader's intent to own the valuable Manghalour Peninsula and subsequent invasion of it can be expressed in the following way.

$$
\begin{aligned}
& \exists t\ \exists t_1\ (\mathbf{now}(t)\ \&\ \mathbf{before}(t_1, t)\ \&\ \mathbf{valuable}(\text{manghalour\_peninsula\_ext} \bullet t_1)\ \& \\
& \quad \mathbf{intends}(\mathbf{president}(\text{orangeland\_nation}) \bullet t_1, \\
& \qquad\qquad \exists t_2\ (\mathbf{before}(t_1, t_2)\ \&\ \mathbf{owns}(\text{orangeland\_nation} \bullet t_2, \\
& \qquad\qquad\qquad\qquad \text{manghalour\_peninsula\_ext} \bullet t_2, \text{united\_nations} \bullet t_2)))\ \& \\
& \quad \exists O\ (\mathbf{military}(O)\ \&\ O \le (\text{orangeland\_nation} \bullet t)\ \& \\
& \qquad \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \le O) \Rightarrow \\
& \qquad\qquad\qquad \mathbf{attached}(X \bullet t, \text{manghalour\_peninsula\_ext} \bullet t))).
\end{aligned}
$$

This assumes the existence of a predicate **valuable**. Valuable means that an economic agreement to exchange a small fragment of it results in the receipt of big dollars.

$$
\begin{aligned}
& \mathbf{valuable}(z \bullet t) =_{df} \\
& \quad (\exists J\ (\mathbf{economically\_agrees}(@(X, t, s_1), @(Y, t, s_2), \\
& \qquad\qquad \exists t_1\ (y \bullet t \le z \bullet t\ \&\ \mathbf{amount}(y \bullet t, \mathbf{extent}(\text{small}))\ \&\ \mathbf{owns}(Y \bullet t_1, J, y \bullet t_1)), J, \mathbf{dollars}(d)) \\
& \quad \Rightarrow \mathbf{amount}(d, \mathbf{extent}(\text{big}))).
\end{aligned}
$$

The economic conflicts within Orangeland can be represented numerically by something like the following

$$
\begin{aligned}
& \exists \alpha\ \exists \beta\ \exists S_1\ \exists S_2\ \exists n_1\ \exists n_2\ \exists n\ \exists m\ ((\mathbf{group}(S_1)\ \&\ \mathbf{group}(S_2)\ \& \\
& \quad S_1 + S_2 \le \text{orangeland\_nation}\ \&\ S_1 \bullet S_2 \equiv \perp\ \&\ \mathbf{population}(S_1, n_1)\ \&\ \mathbf{population}(S_2, n_2)\ \& \\
& \quad \mathbf{population}(\text{orangeland\_nation}, n)\ \&\ (n_1 \div n) > 0.1\ \&\ (n_2 \div n) > 0.1\ \& \\
& \quad \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \le S_1) \Rightarrow \\
& \qquad\qquad \exists Y\ (\mathbf{cognitive}(Y)\ \&\ Y \le S_2\ \&\ \mathbf{conflict}(X, Y, \alpha, \beta)\ \&\ \mathbf{money}(m)\ \& \\
& \qquad\qquad\quad \mathbf{about}(\alpha, m, X)\ \&\ \mathbf{about}(\beta, m, Y)))).
\end{aligned}
$$

or more vaguely by

$$
\begin{aligned}
& \exists \alpha\ \exists \beta\ \exists S_1\ \exists S_2\ \exists n_1\ \exists n_2\ \exists n\ \exists m\ ((\mathbf{group}(S_1)\ \&\ \mathbf{group}(S_2)\ \& \\
& \quad S_1 + S_2 \le \text{orangeland\_nation}\ \&\ S_1 \bullet S_2 \equiv \perp\ \&\ \mathbf{population}(S_1, n_1)\ \&\ \mathbf{population}(S_2, n_2)\ \& \\
& \quad \mathbf{amount}(n_1, \mathbf{small}(\text{medium}))\ \&\ \mathbf{amount}(n_2, \mathbf{small}(\text{medium}))\ \& \\
& \quad \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \le S_1) \Rightarrow \\
& \qquad\qquad \exists Y\ (\mathbf{cognitive}(Y)\ \&\ Y \le S_2\ \&\ \mathbf{conflict}(X, Y, \alpha, \beta)\ \&\ \mathbf{money}(m)\ \& \\
& \qquad\qquad\quad \mathbf{about}(\alpha, m, X)\ \&\ \mathbf{about}(\beta, m, Y)))).
\end{aligned}
$$

The non-economic social conflicts within Orangeland can be represented by the following.

$$
\begin{aligned}
& \exists \alpha\ \exists \beta\ \exists S_1\ \exists S_2\ \exists n_1\ \exists n_2\ \exists n\ \exists m\ ((\mathbf{group}(S_1)\ \&\ \mathbf{group}(S_2)\ \& \\
& \quad S_1 + S_2 \le \text{orangeland\_nation}\ \&\ S_1 \bullet S_2 \equiv \perp\ \&\ \mathbf{size}(S_1, n_1)\ \&\ \mathbf{size}(S_2, n_2)\ \& \\
& \quad \mathbf{size}(\text{orangeland\_nation}, n)\ \&\ (n_1\ /\ n) > 0.1\ \&\ (n_2\ /\ n) > 0.1\ \& \\
& \quad \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \le S_1) \Rightarrow
\end{aligned}
$$

$$
\begin{aligned}
&\exists Y\ (\mathbf{cognitive}(Y)\ \&\ Y \leq S_2\ \&\ \mathbf{conflict}(X, Y, \alpha, \beta)\ \&\ \mathbf{money}(m)\ \&\\
&\quad \neg\mathbf{about}(\alpha, m)\ \&\ \neg\mathbf{about}(\beta, m)))).
\end{aligned}
$$

The Orangeland president's exploitation of national sentiment toward the Manghalour Peninsula can be expressed by the following.

$$
\begin{aligned}
&\forall X\ ((\mathbf{cognitive}(X)\ \&\ X \leq \text{orangeland\_nation}) \Rightarrow\\
&\quad \exists t_1\ \exists s_1\ (\mathbf{offers}(@(\mathbf{president}(\text{orangeland\_nation}), t_1, s_1), @(X, t_1, s_2),\\
&\qquad\quad \exists t_2\ (\mathbf{owns}(@(\text{orangeland\_nation}, t_2, \text{orangeland\_land}),\\
&\qquad\qquad\qquad \text{manghalour\_peninsula\_ext} \bullet t_2)))) \ \&\\
&\exists G\ (\mathbf{group}(G)\ \&\ G \leq \text{orangeland\_nation}\ \&\\
&\quad \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \leq G) \Rightarrow\\
&\qquad\quad \exists t_3\ \exists s_3\ \exists s_4\ (\mathbf{accepts}(@(X, t_3, s_3), @(\mathbf{president}(\text{orangeland\_nation}), t_3, s_4),\\
&\qquad\qquad\qquad \exists t_2\ (\mathbf{owns}(@(\text{orangeland\_nation}, t_2, \text{orangeland\_land}),\\
&\qquad\qquad\qquad\quad \text{manghalour\_peninsula\_ext} \bullet t_2)))).
\end{aligned}
$$

7.3 Ship Situation

Another example from the North Atlantis scenario is the following paragraph ([22]).

> The Redland Kotor class guided missile frigate KOT2 and the two Koncar fast patrol craft KON2 and KON3, have detected submarine activities and moored mines off of the Celtic Straits, and as a consequence they have been boarding merchant ships suspected of carrying military ammunition or explosives to block their access to the straits to prevent a hazardous explosion.

$$
\begin{aligned}
&\{\mathbf{kotor\_ffg}(\text{kot2}), \mathbf{koncar\_fpc}(\text{kon2}), \mathbf{koncar\_fpc}(\text{kon3}),\\
&\ \mathbf{owns}(\text{redland\_nation}, \text{kot2}, \text{united\_nations}), \mathbf{owns}(\text{redland\_nation}, \text{kon2}, \text{united\_nations}),\\
&\ \mathbf{owns}(\text{redland\_nation}, \text{kon3}, \text{united\_nations}),\\
&\exists t_1\ (\mathbf{period}(t_1)\ \&\\
&\ \ \exists t_2\ \exists x\ (\mathbf{period}(t_2)\ \&\ x \leq (\text{kot2} + \text{kon2} + \text{kon3})\ \&\ \mathbf{during}(t_2, t_1)\ \&\\
&\qquad \mathbf{senses}(x \bullet t_2, \exists y\ (\mathbf{submarine}(y)\ \&\ \neg\mathbf{owns}(\text{redland\_nation}, y, \text{united\_nations}))))\ \&\\
&\ \ \exists t_3\ \exists x\ (\mathbf{period}(t_3)\ \&\ x \leq (\text{kot2} + \text{kon2} + \text{kon3})\ \&\ \mathbf{during}(t_3, t_1)\ \&\\
&\qquad \mathbf{senses}(x \bullet t_3, \exists y\ (\mathbf{mines}(y)\ \&\ \neg\mathbf{owns}(\text{redland\_nation}, y, \text{united\_nations})\ \&\\
&\qquad \mathbf{at}(y,\ t_3,\ \text{celtic\_straits\_area}))))\ \&\\
&\ \ \exists t_4\ (\mathbf{period}(t_4)\ \&\ \mathbf{before}(t_1, t_4)\ \&\\
&\quad\ \ \exists C\ (\mathbf{attached}(C \bullet t_4, (\text{kot2} + \text{kon2} + \text{kon3}) \bullet t_4)\ \&\\
&\qquad\ \forall X\ \forall \alpha\ ((\mathbf{cognitive}(X)\ \&\ \mathbf{attached}(X \bullet t_4, (\text{kot2} + \text{kon2} + \text{kon3}) \bullet t_4)) \Rightarrow\\
&\qquad\qquad \mathbf{authority}(C, X, \alpha))\ \&\\
&\quad\ \ \exists t_5\ \exists m\ ((\mathbf{period}(t_5)\ \&\ \text{duration}(t_5, t_4)\ \&\\
&\qquad\qquad \mathbf{believes}(C \bullet t_5,\\
&\qquad\qquad\qquad \mathbf{merchant\_ship}(m \bullet t_5)\ \&\\
&\qquad\qquad\qquad \exists a\ ((\mathbf{ammunition}(a) \vee \mathbf{explosives}(a))\ \&\ \mathbf{attached}(a \bullet t_5, m \bullet t_5)\ \&\\
&\qquad\qquad\qquad\quad \mathbf{approaching}(a, t_5, \text{celtic\_straits}))) \Rightarrow\\
&\qquad\qquad \exists t_6\ (\mathbf{period}(t_6)\ \&\ \mathbf{before}(t_5, t_6)\ \&\ \forall s\ \forall f\ (\neg\mathbf{moves}(m \bullet t_6, s, f))\ \&\\
&\qquad\qquad\qquad \exists t_7\ \exists t_8\ (\mathbf{period}(t_7)\ \&\ \mathbf{period}(t_8)\ \&\ \mathbf{during}((t_7 + t_8), t_6)\ \&\ \mathbf{before}(t_7, t_8)\ \&\\
&\qquad\qquad\qquad\quad \exists G\ (\mathbf{group}(G)\ \&\ \forall X\ ((\mathbf{cognitive}(X)\ \&\ X \leq G) \Rightarrow\\
&\qquad\qquad\qquad\qquad \mathbf{successfully\_commands\_and\_successfully\_achieves}(C \bullet t_6,\\
&\qquad\qquad\qquad\qquad\quad \mathbf{attached}(X \bullet t_7, (\text{kot2} + \text{kon2} + \text{kon3}) \bullet t_7)\ \&\\
&\qquad\qquad\qquad\qquad\quad \neg\mathbf{attached}(X \bullet t_8, (\text{kot2} + \text{kon2} + \text{kon3}) \bullet t_8)\ \&\\
&\qquad\qquad\qquad\qquad\quad \mathbf{attached}(X \bullet t_8, m \bullet t_8)))))))))))))\}.
\end{aligned}
$$

Some of the foregoing is deduced rather than stated, but is included to give greater exposition. Examples of this are:

1. The fact that the Kotor class frigate, for example, is a Redland frigate means that it is owned by Redland. As the ownership is not disputed in the text, the judicial authority for ownership is taken to be the United Nations, and it is assumed that every nation in the scenario is a member of the United Nations.
2. There is a presumed commander C attached to the KOT2, KON2 or KON3. This can be deduced from the fact that these vessels are military vessels and militaries operate with a unity of command policy. Reference to this commander is necessary because someone has decided to board merchant ships given a belief that merchant ships might be carrying ammunition or explosives.
3. It is presumed that the boarded ships are stationary, otherwise they would continue their journey into the Celtic Straits.

8. Conclusions

This document catalogues the concepts currently being considered within the Mephisto framework. Formal semantic theories have been developed for some of the concepts listed and computational implementations also exist for some of the nominated concepts. The Mephisto framework combines a number of existing conceptual frameworks (e.g. Dennett's intentional stance concepts, Pigeau and McCann's command concept, …), formal models (e.g. Allen's theory of time, Stell's Boolean Connection Calculus, …) and computational aspects (e.g. the ISO 8601 standard, the great circle distance models, …), with some new approaches. The ultimate aim is to formulate a computationally feasible conceptual framework. This will require some tradeoffs to be made between philosophical ideology, formal rigour and computational decidability and tractability.

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19. ABSTRACT

This document provides an overview of concepts currently associated with the Mephisto conceptual framework. The Mephisto framework is designed to facilitate machine-based representation and reasoning in the military and national security domains. The conceptualisation introduces metaphysical, environmental, functional, cognitive and social constructs that can be integrated to describe aspects of interest in a military or national security context.